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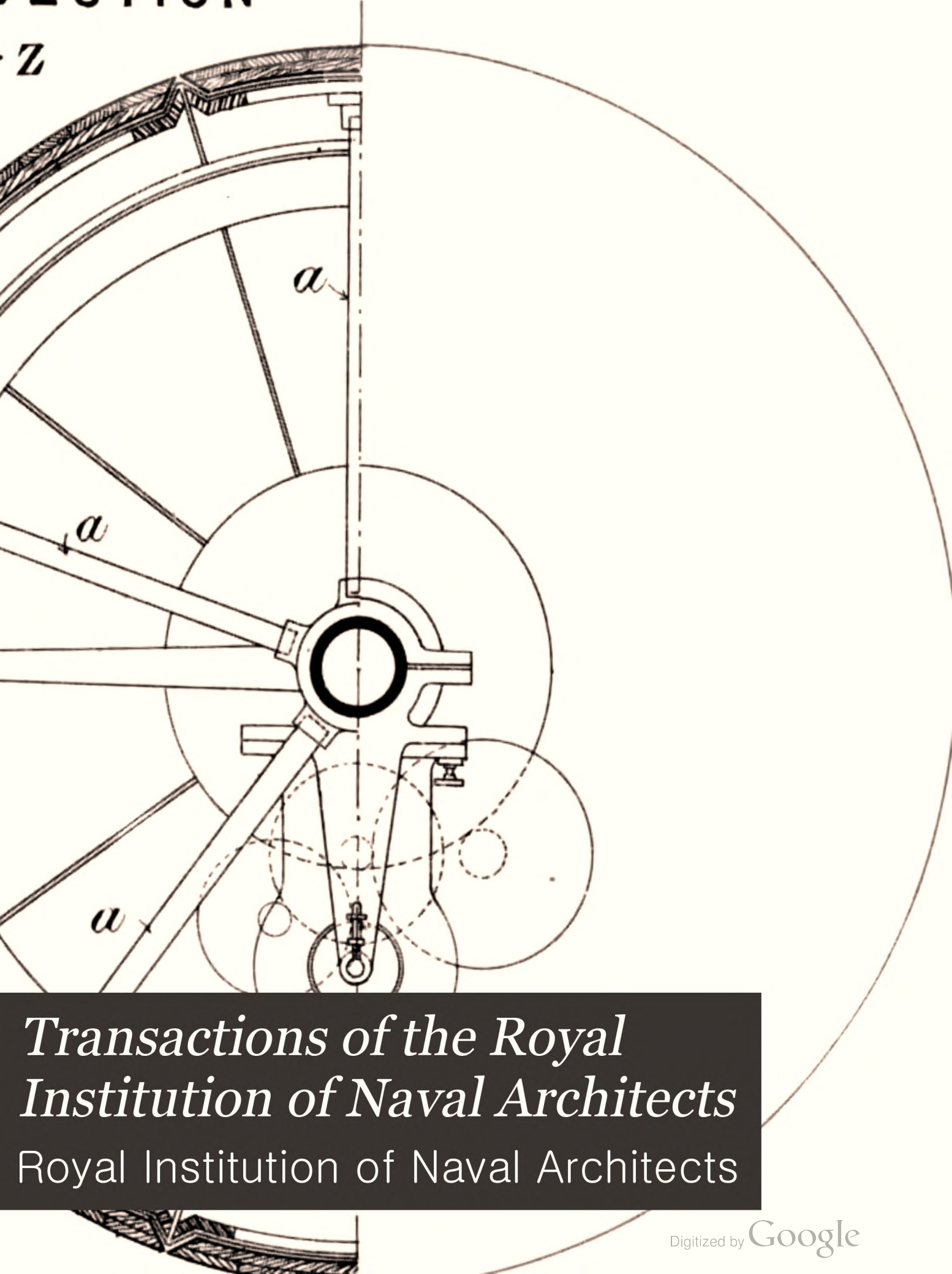

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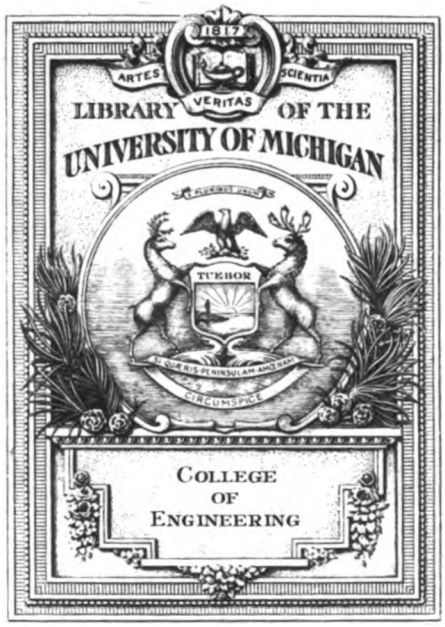

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Urtubey, Clodomiro, Rear-Admiral, Argentine Navy
Utley, T.

Van Raalte, J.
Vavasseur, Josiah
Vickers, A.

Wade, W. S.
Wait, A. M.
Walker, W., Colonel, V.D., J.P.
Watkinson, W. H., Professor
Watson, H. Burnett
Watson, Henry James
Watson, W.
Watson, Sir William
Watt, John
Watts, Edmund H.
Watts, Fenwick Shadforth
Webster, M. P.
Weidemann, Christopher
Westmacott, Percy G. B.
Wharton, Sir William J. L., K.C.B., F.R.S., Rear-Admiral
White, J. Bell
White, Robert
Wiegand, H.
Willard, C. D.
Williams, R. W.
Williams, Samuel
Williamson, R. H
Wills, W.
Wilmot, S. Eardley, Captain, R.N.
Wilson, Sir Alexander, Bart.
Wilson, A. G.
Wilson, A. K., Rear-Admiral, V.C., C.B.
Wilson, H. C.
Wilson, W. G.
Wingfield, G. J., Com. R.N.
Wise, William Lloyd
Woodall, J. W.
Wort, W. E.
Wylie, R.
Wylie, William

Yamamoto, N.
Younger, Rober L.

Ziffer, J. H.

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OBJECTS OF THE INSTITUTION.

THE objects of the INSTITUTION OF NAVAL ARCHITECTS—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads :—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our Navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. THE INSTITUTION OF NAVAL ARCHITECTS shall consist of three classes, viz., Members, Associates, and Honorary Members.

2. *Members.*—The class of Members shall consist exclusively of Naval Architects, and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

5. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council) a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

6. A General Meeting of the Members and Associates of the Institution shall be held annually before Easter in each year; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

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7. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the election of Associate Members of Council, the Treasurer, and the Auditors.

8. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

9. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

10. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present to preside.

11. The Chairman at any Meeting of the Council of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

12. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

13. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

14. *Members of Council.*—Members only shall be eligible for election as Members of Council at the Annual General Meeting.

15. *Associate Members of Council.*—Associates only shall be eligible for election as Associate Members of Council at the Annual General Meeting.

16. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

17. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of the Council shall form a *quorum*.

18. The Council may appoint Committees to report to them upon special subjects.

19. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding meeting of the Council.

20. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and, after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

21. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

22. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

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23. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council and are still Members of the Institution, shall be eligible for election as Treasurer.

24. *Trustees.*—There shall be four Trustees, two of whom shall be the President and Treasurer of the Institution for the time being. The remaining two shall be appointed by, and hold office at the pleasure of the Council. In the names of these trustees, under the direction of the Council of the Institution, all securities shall be taken and investments made, the whole of such property being notwithstanding subject to the disposition of the Council, and the order of the Council in writing, signed by the Chairman of the Meeting and countersigned by the Secretary, shall be obligatory upon and full authority for the Trustees.

25. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

26. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

27. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

29. In each year six Ordinary and two Associate Members of Council shall retire, unless before the date of drawing up the Balloting Lists for the election of the Council any Members of the Council shall have died or resigned, in which case only so many members shall retire as shall be necessary in order to make up the number to six Ordinary and two Associate Members of Council, subject always to the provisions of Rule 36. The Members who shall retire in each year shall be those who have served longest on the Council from the date of the last election, and in the event of there being several Members who have served an equal time on the Council, the order of retirement amongst these shall be alphabetical. The retiring Members shall be eligible for re-election.

30. In January of each year the Council shall meet and prepare Lists for the election of the Council for the ensuing year. These Lists shall be as follow, namely :—

1*st.* A List of the names of the President, Vice-Presidents, and Treasurer for the ensuing year to be submitted at the Annual General Meeting, for their election in a body.

2*nd.* A list of candidates to fill any vacancies in the list of Vice-Presidents that it may be intended to fill up from among the professional Members of the Institution.

3*rd.* Lists for the election of the Ordinary Members and Associate Members of Council.

31. No addition shall be made to the list of Vice-Presidents until, by death or resignation, their number shall have been reduced to below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. The vacancies are to be filled up in such a manner that not less than one-half nor more than two-thirds of the total list of Vice-Presidents shall be professional Members of the Institution. Provided

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always that the Council shall be at liberty, should special circumstances arise before the numbers shall have been reduced below twenty-four, to provide for the election of one Member and one Associate of the Institution as Vice-Presidents.

32. When any vacancy occurs in the list of Vice-Presidents which it is intended to fill by the election of a professional Member of the Institution, the election shall be by voting papers issued to all Members of the Institution. The candidates to fill the vacancy shall be selected by the Council in the month of January from among the existing or past Members of Council. The number of candidates shall not be less than two for each vacancy, but shall not otherwise be limited. The voting papers shall be issued to the members at the same time as the voting papers for the election of Members of Council, and shall be subject to the same regulations and scrutiny as these latter, as provided for by Rules 37, 38, 39, 40.

33. After having been once elected by voting papers, the Vice-Presidents will be subject to re-election every year in a body at the Annual Meetings.

34. When any vacancy occurs in the list of Vice-Presidents which it is intended to fill by the election of an Associate of the Institution, the nomination to fill the vacancy shall be made by the Council, and the candidate nominated shall be included in the list of Vice-Presidents submitted at the Annual Meetings for election in a body.

35. No addition shall be made to the total number of Ordinary Members of the Council until, by death of resignation, their numbers shall have been reduced below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. And no addition shall be made to the Associate Members of Council until, by death or resignation, their numbers shall have been reduced below eight, after which their numbers shall be raised to and preserved at eight, always exclusive of the President, Vice-Presidents, and Treasurer.

36. At the date of issuing the Syllabus of the Annual General Meetings in each year, the Lists proposed by the Council for the election of Members to fill the vacancies in the Ordinary Council for the ensuing year shall be printed, and sent to all Members to serve as Balloting Lists. These Lists shall contain, first, the names of the retiring Ordinary Members of Council at the time of the preparation of the Balloting List, together with as many new names of Members of the Institution as shall be needed to bring the number up to twice the number of vacancies, and the whole of these names shall be printed in alphabetical order. Secondly, the names of the retiring Associate Members of Council at the time of the preparation of the Balloting List, together with as many new names of Associates of the Institution as shall be needed to bring the number up to twice the number of vacancies, and these names also shall be printed in alphabetical order. From these Lists the vacancies in the Council shall be filled up. Every Member shall be at liberty to vote for as many names on each of the Lists as there are vacancies to be filled, but not for more.

37. A similar Balloting List (in which, however, the names of the Ordinary Members of Council proposed for election shall not be included) shall be printed and sent to all Associates of the Institution, to serve as a Balloting List for Associates, from which the voting for Associate Members of Council shall be taken. Every Associate shall be at liberty to vote for as many names on that List as there are vacancies to be filled, but not for more.

38. The Balloting Lists may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be personally presented by the Members and Associates at the opening of the Annual General Meeting.

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39. At the opening of the Annual General Meeting the order of business shall be :—

(1) To read and consider the Reports of the Council and Treasurer.

(2) To read the List of Officers and Nomination for Council for the ensuing year, proposed by the Council.

(3) The Chairman shall next put to the Meeting the List containing the names of the President, Vice-Presidents, and Treasurer for election for the ensuing year.

(4) The Chairman shall then nominate two Scrutineers (of whom one only shall be a Member of the existing or proposed Council), and shall hand to them the Ballot Boxes containing the Voting Papers for the Ordinary Members of Council and Associate Members of Council ; and

(5) The Scrutineers shall receive all Ballot Papers which may have reached the Secretary, and all others which may be presented by Members or Associates at the Meeting. The Scrutineers shall then retire and verify the Lists, and count the votes ; and shall, not later than the following day, report to the Chairman the names which have obtained the greatest number of votes, subject to the conditions of the Ballot. The Chairman shall then read the List presented by the Scrutineers, and shall declare the gentlemen named in the List to be duly elected, provided always that the List does not contain more names than there are vacancies to be filled. If, in consequence of two or more of the candidates receiving an equal number of votes, the List shall contain more names than there are vacancies, the Council shall, at their next meeting, decide which of these candidates shall be elected.

(6) After the Ballot shall have been taken, and the Scrutineers have retired, the Meeting will proceed to the other business before it.

40. The new Council and Officers shall take office immediately after the close of the Annual General Meeting.

41. In the event of any vacancy occurring in the offices of either President or Treasurer after the date of the Annual Election in any year, the Council shall have power to elect a new President or Treasurer as the case may be, who shall hold office till the conclusion of the next Annual General (Spring) Meeting of the Institution.

DESIGNATION OF MEMBERS AND ASSOCIATES.

42. Any Member, Associate, or Honorary Member, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, viz., M.I.N.A. ; Assoc. I.N.A. ; Hon. Mem. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

43. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulations :—

He shall submit to the Council a statement showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, or Marine Engineer conversant with Naval Architecture, and to be admitted as such to the Membership of the Institution. This shall be

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signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

44. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, his proposal for admission shall be submitted to the Members of the Institution (who shall have access to the applicant's statement), at an Ordinary Meeting of the Institution, for them to vote upon, the voting to be by ballot, should a ballot be demanded.

45. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon, the voting to be by ballot, should a ballot be demanded.

46. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

47. Each Member and Associate shall pay an Entrance Fee of two guineas, and an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

48. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

49. No person's name shall be entered on the Roll as Member or Associate of the Institution nor possess the privileges of Membership (except it be on the honorary list) until he shall have paid his first subscription or the life composition, and if the payment be delayed for more than twelve months from the date of his election, the same shall be void unless the Council otherwise direct.

50. The Secretary shall at the close of every year notify to all Members and Associates whose subscription for that year shall not have been paid, that it will be his duty to report accordingly to the Council, and he shall at the same time furnish the person whose subscription is in arrear with copies of this and the two following Rules.

51. The Secretary shall before Easter in every year lay before the Council a list of all Members and Associates whose subscriptions for the two previous years shall be still unpaid, and unless the Council shall otherwise direct, the names of those in arrear shall be expunged from the Roll of Members and Associates, and shall not be replaced without re-election in due form. Provided always that the Council shall at any time within two years therefrom have power to dispense with such re-election, and to restore the name to the Roll upon payment of all subscriptions then due, and upon cause being shown to the satisfaction of the Council why such subscriptions were not previously paid.

52. Nothing herein contained shall prejudice the right of the Institution to the legal recovering of all arrears of subscriptions up to the date of striking the name off the Roll.

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53. In case the Council shall be of opinion that any Member, who has been long distinguished in his professional career, from ill-health, advanced age, or other sufficient causes, should not be called upon to continue his annual subscription, they may remit it. Also they may remit any arrears which are due from an individual, or may accept a collection of books, or drawings, or models, or other such contribution as, in their opinion, under the circumstances of the case, may entitle the person to be enrolled as a Life Subscriber, or to enable him to resume his former rank in the Institution which may have been in abeyance from any particular causes. These cases must be considered and reported upon by a Sub-Committee named for the purpose.

54. In case the expulsion of any individual shall be judged expedient by ten or more Members, and they think fit to draw up and sign a proposal requiring such expulsion, the same being delivered to the Secretary shall be by him laid before the Council. If the Council, after due inquiry, do not find reason to concur in the proposal, no entry thereof shall be made in any Minutes, nor shall any public discussion thereon be permitted; but if the Council do find good reason for the proposed expulsion they shall direct the Secretary to address a letter to the person proposed to be expelled, advising him to withdraw from the Institution. If that advice be followed, no entry on the Minutes nor any public discussion on the subject shall be permitted; but if that advice be not followed, nor a satisfactory explanation given, the Council shall call a Special General Meeting of Members and Associates, for the purpose of deciding on the question of expulsion; and if two-thirds of the persons present at such Special General Meeting, providing the number so present be not less than thirty, vote that such individual be expelled, the Chairman of that Meeting shall declare such expulsion accordingly, and the Secretary shall communicate the same to the individual.

MEETINGS.

55. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

56. The *Transactions* of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

57. A copy of each Volume of *Transactions* shall be sent free to every Member and Associate.

58. The Secretary, under the direction of the Council, may dispose of the surplus stock of *Transactions* which have been published more than three years, at a price of not less than One Guinea a volume, provided a sufficient number remain on hand to supply the probable demand of New Members and Associates to complete their sets by the purchase of the back Volumes.

CHANGE OF ADDRESS.

59. Members and Associates are particularly requested to communicate to the Secretary any change of address.

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PROCEEDINGS IN LONDON.

SPRING MEETINGS OF THE THIRTY-NINTH SESSION

OF THE

INSTITUTION OF NAVAL ARCHITECTS.

MARCH 30, 31, AND APRIL 1, 1898.

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INTRODUCTORY PROCEEDINGS.

THE Spring Meetings of this, the Thirty-ninth Session of the Institution of Naval Architects, were held on March 30, 31, and April 1, 1898, in the Hall of the Society of Arts, John-street, Adelphi, W.C.

The opening meeting was presided over by the Right Hon. the Earl of Hopetoun, G.C.M.G., President of the Institution, who commenced the proceedings by calling on the Secretary, Mr. George Holmes, to read the Report of the Council, which was as follows:—

ANNUAL REPORT OF COUNCIL, 1898.

The Council reports, with much pleasure, that the past year has been one of great activity, during which the Institution has made satisfactory progress. Its finances, as shown by the annexed statement of receipts and expenditure, are in a sound condition. During the year, 151 new members and associates were elected; while the losses, due to death and resignation, amounted to 25, leaving a net increase of 126.

It was announced in the last Annual Report that the Council had arranged to celebrate the sixtieth year of the reign of Her Majesty the Queen, by holding an International Congress of Naval Architects and Marine Engineers in London. The Council have now to report that the Congress was held under most favourable circumstances in the month of July last. The Governments and Navies of almost all the Maritime States in the World were represented, and the Institution had further the satisfaction of welcoming to this country the Committees who had received us with such unbounded hospitality and kindness in Paris, Hamburg, and Berlin; also representatives from the Society of Naval Architects and Marine Engineers of the United States; from the Société des Ingénieurs Civils de France; the Association Technique Maritime; the German Institution of Civil Engineers, and a number of our foreign members and associates.

His Royal Highness the Prince of Wales, who had graciously consented to become Honorary President of the Congress, opened the proceedings at the Imperial Institute, on Tuesday, July 6. Their Royal Highnesses the Duke of Saxe-Coburg and the Duke of York most kindly accepted invitations to become Honorary Vice-Presidents, as also did the Right Hon. George J. Goschen, M.P., First Lord of the Admiralty, and the Right Hon. C. T. Ritchie, M.P., President of the Board of Trade.

A large and representative Reception Committee was formed, composed principally of Members of the Institution, but which also included the late Lord Mayor of London, Alderman Sir George Faudel-Phillips, Bart, G.C.I.E., the Hon. Lord Provost Richmond of Glasgow, and many other

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gentlemen not connected with the Institution, who rendered invaluable services in the reception and entertainment of the guests, and to whom the best thanks of the Institution are due.

Her Majesty the Queen conferred the highest distinction on the Congress by graciously receiving the members at Windsor Castle on Saturday, July 10.

The papers read at the meetings, and a record of the excursions and entertainments, together with other particulars relating to the organisation and work of the Congress, are published in a separate volume of the Transactions, which has been already distributed.

This volume contains also the expression of the grateful thanks of the Council to all those who assisted it in the work of the Congress and the reception of the guests. Without this assistance, which was freely and generously given, the Congress could not have been brought to a satisfactory conclusion.

The Council have received from the foreign representatives at the Congress many letters and illuminated addresses couched in the warmest terms, which they thankfully acknowledge. These communications have also been published in the special volume of the Transactions, and will be preserved amongst the most valued archives of the Institution. As a memorial of their visit to Great Britain the representatives from Hamburg and Bremen have most kindly presented a handsome piece of plate to the Institution, which has been gratefully accepted as a mark of the esteem and goodwill of the donors.

The Council have, after full consideration, determined not to hold a Summer Meeting during the current year.

The Council have had great pleasure in awarding a premium to Mr. Sydney Barnaby for his paper, "On the Formation of Cavities in Water by Screw Propellers at high Speeds"; and a similar premium to Mr. Alexander Ramage for his two papers, "A mechanical Method of ascertaining the statical Stability of Ships," and "On the Use of the mean Water-line in designing the Lines of Ships."

The vacancy in the representation of the Institution on the committee appointed to assist the Marine Department of the Board of Trade, caused by the death of Mr. Alfred Blechynden, which was reported last year, has been filled by the election of Mr. John Sampson, of Messrs. Maudslay, Sons & Field, who has kindly consented to act.

The Council announce, with much regret, the death of Admiral Popoff, who was an honorary member of the Institution; and of Mr. Richard Barnwell, late managing director of the Fairfield Shipbuilding and Engineering Company, Limited.

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Institution of Naval Architects.

Dr. *Statement of Receipts and Payments for the Year* 1897. Cr.

Receipts.	£ s. d.	£ s. d.	Payments.	£ s. d.	£ s. d.
To Balance at Banker's, Dec. 31, 1896	318 2 5		By Rent	220 0 0	
,, Balance in Secretary's hands, Dec. 31, 1896	37 18 11		,, Bankers' Charges	2 3 11	
		356 1 4	,, Stationery...	29 16 0	
,, Annual Subscriptions		2,585 12 11	,, Auditors' Fee	5 5 0	
,, Life Subscriptions		220 10 0	,, Salaries and Wages	1,153 1 8	
,, Admiralty Grant		250 0 0	,, Investment in 2¾ per cent. Consols	752 14 3	
,, Sales of Volumes		141 12 3	,, Housekeeper and Cleaning ...	37 14 0	
			,, Despatch of Volumes	62 19 9½	
			,, Petty Disbursements	32 7 1	
			,, Postages and Telegrams... ...	39 17 0½	
			,, Insurance	2 10 0	
					2,318 8 9
			,, Expenses of Spring Meetings ...	67 16 4	
			,, Miscellaneous	10 0 0	
			,, Gold Medals and Premium ...	34 1 8	
					111 18 0
			,, Reporting Spring and Summer Meetings	80 0 0	
			,, Printing Volume XXXVIII. and Circulars	707 6 7	
			,, Translating	9 7 0	
			,, Advertising	7 12 6	
					804 6 1
			,, Balance at Banker's Dec. 31, 1897	247 17 4	
			,, Balance in Secretary's hands to meet Current Expenses, Dec. 31, 1897	71 6 4	
					319 3 8
		£3,553 16 6			£3,553 16 6

LIBRARY FUND.

Receipts.	£ s. d.	Payments.	£ s. d.
To Balance at Banker's, December 31, 1896 ...	46 14 2	By Library Expenses	14 16 1
,, Entrance Fees	315 0 0	,, Furniture and Repairs	25 16 1
,, Dividends on Investments	158 12 8	,, Investments 2¾ per cent. Consols	400 0 0
		,, Balance at Banker's, December 31, 1897 ...	79 14 8
	£520 6 10		£520 6 10

H. MORGAN, Honorary Treasurer.
GEORGE HOLMES, Secretary.

We have examined the above-written entries with the books and vouchers, and find them correct.

BALL, BAKER, DEED, CORNISH & Co.,
Chartered Accountants.

March 9, 1898.

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The following is a List of Donations to the Library :—

"Transactions of the Liverpool Engineering Society," for 1897. *Presented by the Liverpool Engineering Society.*

"Minutes of the Proceedings of the Institution of Civil Engineers," Vols. CXXVIII., CXXIX., CXXX., and CXXXI. *Presented by the Institution of Civil Engineers.*

"Proceedings of the Institution of Mechanical Engineers," for 1897. *Presented by the Institution of Mechanical Engineers.*

"Journal of the Iron and Steel Institute," for 1897. *Presented by the Iron and Steel Institute.*

Index to the "Journal of the Iron and Steel Institute," Vols. I. to L., 1869 to 1896. *Presented by the Iron and Steel Institute.*

"Journal of the Society of Arts," for 1897. *Presented by the Society of Arts.*

"Transactions of the Institution of Engineers and Shipbuilders in Scotland," Vols. XXXIX. and XL., 1896-97. *Presented by the Institution of Engineers and Shipbuilders in Scotland.*

"Transactions of the Society of Engineers," for 1897. *Presented by the Society of Engineers.*

"Transactions of the Institute of Marine Engineers for 1896-97. *Presented by the Institute of Marine Engineers.*

"Transactions of the North-East Coast Institution of Engineers and Shipbuilders," Vol. XIII., 1896-97. *Presented by the North-East Coast Institution.*

"Transactions of the American Society of Mechanical Engineers," 1897. *Presented by the Council of the American Society of Mechanical Engineers.*

"The Scientific Proceedings of the Royal Society of Dublin," for 1897. *Presented by the Royal Society of Dublin.*

"Journal of the United States Artillery." *Presented by the Editor of the Journal.*

"Transactions of the Junior Engineering Society," Vol. VI., 1896. *Presented by the Junior Engineering Society.*

"Bulletin de l'Association Technique Maritime, Session 1896-7." *Presented by l'Association Technique Maritime.*

"Transactions of the Society of Naval Architects and Marine Engineers," Vol. V., 1897. *Presented by the Society of Naval Architects and Marine Engineers.*

"Bulletin de la Société Scientifique et Industrielle de Marseille," 1897. *Presented by the Editor.*

"The Journal of the Franklin Institute," for 1897. *Presented by the Franklin Institute.*

"Proceedings of the United States Naval Institute," for 1897. *Presented by the U.S. Naval Institute.*

"Proceedings of the Royal Society of New South Wales," Vol. XXX., 1896. *Presented by the Royal Society of New South Wales.*

"Transactions of the North of England Institute of Mining and Mechanical Engineers," for 1897. *Presented by the North of England Institute of Mining and Mechanical Engineers.*

"Transactions of the Hull and District Institution of Engineers and Naval Architects," for 1897. *Presented by the Hull and District Institution of Engineers and Naval Architects.*

"Lloyd's Register of British and Foreign Shipping," 1897-98. *Presented by the Committee of Lloyd's Register.*

"Lloyd's Register of Yachts," for 1897-98. *Presented by the Committee of Lloyd's Register.*

"Annual Report of the Royal National Lifeboat Institution," 1897. *Presented by the Royal National Lifeboat Institution.*

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Portrait of Sir William White, K.C.B., LL.D., Sc.D., F.R.S. *Presented by* Mr. G. B. BLACK, *Portrait Painter, Haymarket.*

"Report of the Chief of the Bureau of Ordnance to the Secretary of the (U.S.) Navy, 1896." *Presented by the* Hon. T. A. BRASSEY.

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"Das Stabilitäts-Problem." *Presented by the Author*, Herr L. GÜMBEL. *Pamphlet.*

"Lines from my Log-Book." *Presented by the Author*, Admiral the Right Hon. Sir JOHN DALRYMPLE-HAY, Bart., K.C.B., D.C.L., F.R.S.

"French and Italian Naval Estimates for the Year 1897." *Presented by the* Hon. T. A. BRASSEY.

"Marine da Guerra del Mondo l'Officier de Marine, 1897." *Presented by the* Hon. T. A. BRASSEY.

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"Notes on American Iron and Steel Practice." *Presented by the Author*, A. P. HEAD, Esq. *Pamphlet.*

"Description of No. 3 Graving Dock, Glasgow." *Presented by the Author*, JAMES DEAS, Esq. *Pamphlet.*

"Photo Group of the Members of the Institution of Naval Architects at the Annual Dinner, Hotel Cecil, March 30, 1898." *Presented by the Photographers*, Messrs. FRADELLE & YOUNG, Regent-street, W.

Photographs of Members of the Institution. *Presented by Messrs. Maull & Fox, photographers, Piccadilly.*

The following gentlemen having been duly recommended by the Council were unanimously elected Members of this Institution:—Mr. Robert Allan, Partner in the firm of Messrs. Riley, Hargreaves & Co., Engineers and Shipbuilders, Singapore; Mr. Robert Baylis Armstrong, Engineering Manager to Messrs. Day, Summers & Co., Southampton; Mr. William Barrie, Superintendent Engineer and Manager to the Nitsu Bishi Company, Japan; Mr. Walter Carl Bergius, Partner in the firm of Messrs. Walter C. Bergius & Co., Engineers and Naval Architects, Glasgow; Mr. Frank Robertson Blair, Chief Draughtsman to Messrs. Gourlay Bros. & Co., Dundee, N.B.; Señor Adolfo Garcia Cabezas, Professor of Naval Architecture in the Provincial Science and Art School, Cadiz; Mr. James Chalmers Clark, Assistant Manager to Messrs. George Clark, Limited, Sunderland; Mr. Alfred William Cock, Admiralty Overseer at the Works of the London and Glasgow Ship and Engineering Company, Glasgow; Mr. Henry J. de Cordemoy, Inspector-in-Chief at the Fairfield Shipbuilding and Engineering Company, Limited, Govan; Mr. William Richard Benison Day, Superintendent in the Shipyard of Sir William Armstrong & Co., Whitworth & Co., Ltd.; Mr. Guy William Edwards, Partner in the firm of Messrs. H. S. Edwards & Sons, Dry Dock Owners, Ship Repairers, and Engineers, South Shields; Mr. John Waterman Earle, Managing Director to Messrs. Edwin Clark & Co., Limited, Engineers, Yacht and Launch Builders, Stroud, Gloucestershire; Mr. James Ferguson, Engineer and Shipwright Surveyor to the Government at Bombay; Mr. Mumanosuke Fukuda, Naval Constructor in the Japanese Navy; Mons. Gustave Casimir Adrien Guillaume, Constructor in the French Navy, Toulon; Mr. William Gallon Hunter, Chief Naval Constructor to the Chantiers Navals de Nicolaieff, Russia; Mr. George Idle, Naval Architect and Surveyor of Shipping to the Commissioners of Irish Lights, Dublin; Mr. Joshua Hyde Irwin, General Manager and Director to the North-Eastern Marine Engineering Company, Limited, Sunderland; Mr. Alexander Jack, of Messrs. Day, Summers & Co., Southampton; Mr. William Charles Jack, Engineer-in-Chief and Works Manager to the "Service Subventionné des Correspondances Fluviales au Tonkin; Herr Ludwig Louis Jeronite, Assistant Constructor at I.R. Dockyard, Vola, Austria; Mr. William Johnson, Managing Director in the firm of Messrs. Forrest & Son, Limited, Shipbuilders, Wyvenhoe, Essex; Mr. John George Kincaid, Senior Partner in the firm of Messrs. John G. Kincaid & Co., Greenock; Mr. Robert Leslie, Manager of the P. & O. Company's Repairing Works, London; Mr. John Patrick Lowson, Chief Draughtsman to Messrs. Workman, Clark & Co., Limited, Belfast;

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Mr. Andrew Macfarlane, Consulting Engineer and Marine Surveyor, Sunderland; Mr. Nicol MacNicoll, Naval Architect and Marine Surveyor, Glasgow; Herr Victor Stanislaus Nawatzki, Manager at the Bremer Schiffsbaugesellschaft Vegesack; Mons. Vladimir Christianowitch Offenberg, Chief Naval Architect of the Baltic Shipbuilding and Engineering Works, St. Petersburg; Captain Gioacchino Russo, Naval Architect in the Royal Italian Navy, Rome; Mr. Herbert Charles Sadler, Assistant to Professor J. H. Biles at Glasgow University; Mr. Frederick Shepherd, of Messrs. Long & Cornwallis, Piccadilly, W.; Mr. Robert George Snell, Assistant to the Superintending Engineer P. & O. Dockyard, Bombay; Mr. Albert Sheerman Swan, Naval Architect and Surveyor, Newcastle-on-Tyne; Mr. Ernest Blakelock Thubron, Managing Owner of the Boulac Engine Works, Cairo; Mr. Shunjiro Tomioka, Surveyor in Japan to the British Corporation; Herr Carl Georg Warburg, Surveyor to the London Salvage Association, Copenhagen; Mr. Josiah Clement Wedgwood, Assistant Constructor at the Elswick Shipyard; Mr. Thomas Richard Williams, Chief Naval Constructor to the Chantiers Navals, &c., Nicolaieff; Herr Henry Zweig, Naval Constructor in the Imperial and Royal Austro-Hungarian Navy.

The following gentlemen were elected Associates:—Mr. Marcus Samuel Abrahams, Professor Archibald Barr, Captain A. Bianco, Royal Italian Naval Attaché, the Hon. James Cleland Burns, Mr. James Craig, jun., Mr. Frederick Eliot Duckham, Professor Stanley Dunkerley, Captain A. Fiéron, French Naval Attaché; Mr. John Hazell Fraser, Mr. Edward Fudger, Mr. Frank Edward Hardcastle, Mr. Edward Hain, Mr. James Hummel, Mr. William Van Sittart Howard, Mr. Alfred Jenkins, Mr. Charles Alfred Knight, Mr. Dionysius Stanislaus Lardner, Herr Franz Joseph Meyer, Captain Arthur William Moore, R.N., C.B., C.M.G., Mr. Robert Wright Shillington, Mr. Frederick Henry Smith, Mr. Frederick Seaton Snowdon, Señor Juan Garcia de Sola, Mr. Alexander George Wilson, Mr. William Wylie.

Since the issue of Volume XXXVIII., the Institution has sustained the loss of the following gentlemen:—Mr. Stephen Alley, Mr. E. N. Coomber, Mr. G. B. Haynes, Mr. D. Meiklereid, Mr. Thomas Mudd, Mr. Cuthbert Potts, Mr. Archibald Thomson, Mr. T. F. Unwin, Mr. W. Watson, Members; Mr. R. Barnwall, Mr. Matthew Cay, Mr. J. Darling, Herr J. Meyer, Associates.

The Secretary next read the following list of names of the retiring Members, and the new names nominated by the Council to fill up the vacancies for the Ordinary and Associate Members of Council for the ensuing year. Retiring Members of Council:—Mr. H. E. Deadman, Sir William Gray, Mr. R. H. Humphrys, Mr. J. Rodger Thomson. New candidates nominated for Members of Council:—Mr. Alexander Adamson, Mr. Sydney W. Barnaby, Mr. R. R. Bevis, Mr. A. Holt, The Right Hon. W. J. Perrie, Mr. H. G. Spence, Mr. C. E. Stromeyer, Mr. J. Williamson. Retiring Associate Members of Council:—Mr. T. H. Ismay and Mr. James Riley. New candidates nominated for Associate Members of Council:—Vice-Admiral Sir Nathaniel Bowden Smith, K.C.B., and Mr. Charles E. Ellis.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.) next put to the Meeting the following list containing the names of the President, Vice-Presidents, and Treasurer for the ensuing year, which was unanimously adopted. President—the Right Hon. the Earl of Hopetoun, G.C.M.G. Past Presidents—the Right Hon. the Earl of Ravensworth; the Right Hon. Lord Brassey, K.C.B., D.C.L. Vice-Presidents—H.R.H. Duke Alfred of Saxe-Coburg and Gotha, K.G., K.T., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E., Admiral of the Fleet; the Right Hon. the Earl of Northbrook, G.C.S.I.; the Right Hon. the Earl of Ravensworth; the Right Hon. Earl Spencer, K.G.; the Right Hon. Lord Armstrong, C.B., D.C.L., F.R.S.; the Right Hon. Lord George Hamilton, M.P.; the

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Right Hon. Lord John Hay, G.C.B., Admiral of the Fleet; the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Admiral; Sir Nathaniel Barnaby, K.C.B.; Sir Frederick Bramwell, Bart., D.C.L., F.R.S.; Sir John Durston, K.C.B., R.N.; Sir Frederick W. E. Nicolson, Bart., C.B., Admiral; Sir Edward J. Reed, K.C.B., F.R.S.; Sir W. H. White, K.C.B., LL.D., Sc.D., F.R.S.; Sir James Wright, C.B.; F. K. Barnes, Esq.; James Dunn, Esq.; F. Elgar, Esq., LL.D., F.R.S.; Benjamin Martell, Esq.; Henry Morgan, Esq. (Treasurer); George W. Rendel, Esq.; J. I. Thornycroft, Esq., F.R.S.; W. H. Tindall, Esq.; A. F. Yarrow, Esq.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): I have the pleasure now, gentlemen, to present the premiums referred to in the Annual Report, to Mr. Sydney Barnaby and to Mr. G. Ramage, and I congratulate them upon having written papers which have earned this distinction.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, before proceeding to the formal business of the day, a pleasant duty has fallen upon me. It is, the duty of presenting, on behalf of the Council of the Institution, this souvenir to our excellent Secretary and friend, Mr. Holmes; a souvenir of the important events of last summer, to which I have already referred. Mr. Holmes, by his gentleness, his urbanity, his patience, has endeared himself to all of us. He has worked heart and soul for the good of the Institution, and probably none of us have had a better opportunity than I have, myself, of knowing how hard, and how laborious, his labours were during last summer. I can only say, and in this I know you will agree with me, that we are extremely grateful to him for the way in which he has worked for us, at the sacrifice of his time, his convenience, and his health. Now, gentlemen, Mr. Holmes is a sensitive man, and would not wish me, I am certain, to say much more in his presence; but on your behalf I present him with this handsome piece of silver, and with it I convey to him your best wishes for his health and happiness, and for the health and happiness of those near and dear to him.

Mr. GEORGE HOLMES: My Lord and Gentlemen, I thank you from my heart for your beautiful gift, and for the more than kind words with which you have accompanied it. I shall always value this piece of silver among the best of my possessions, not only for its great beauty and intrinsic worth, but also because of the many pleasant memories and associations which will always be connected with it; memories of a time, I hope, that we all enjoyed, but memories also of the consideration, indulgence, and kindness with which you have always treated my many shortcomings. I thank you very much.

The PRESIDENT then nominated Professor J. H. Biles, Member of Council, and Mr. J. Ward, Member, as Scrutineers to examine the voting papers.

The PRESIDENT (the Right Hon. the Earl of HOPETOUN, G.C.M.G.) then proceeded to deliver the following Opening Address:—It has been my good fortune since I had the honour to become President of this Institution to be able to congratulate the Council and the Members upon the satisfactory nature of our Annual Reports. I do not think that the Report just presented falls short, in any respect, of the high level reached by its predecessors; indeed, in my judgment it surpasses them all. It is, in some respects, a superlative report: it is short and concise, but it contains paragraphs which have reference to some of the most important events which have happened to us since our inception as a corporate body. Our monetary position is a sound one, and the number of members on our rolls is steadily increasing year by year.

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I do not think that we are likely to forget the events of last July. To some of us, on whom the pressure of responsibility for the complete success of the great Congress rested, the contemplation of a satisfactory retrospect may not be the least enjoyable part of the proceedings. But we feel that such a pleasing retrospect would be impossible, had we not received the loyal co-operation and the unstinted support of all the Members of our body, and we, as officers of the Institution and Members of the Council, cannot feel sufficiently grateful for that support and co-operation.

The Institution will always entertain feelings of the deepest and most respectful gratitude towards Her Majesty the Queen for her gracious kindness towards us, and for the countenance and encouragement which she extended to our work.

Neither can we forget that His Royal Highness the Prince of Wales was pleased, in the midst of his many engagements at that most busy season, to honour us with his patronage and presence. To Their Royal Highnesses the Duke of Saxe-Coburg-Gotha and the Duke of York we are also deeply indebted for the interest which they took in our proceedings.

From the First Lord of the Admiralty, and last, not least, from Lord Salisbury, as Secretary of State for Foreign Affairs, we received help and support so priceless that it is not possible to express within the limits permitted to me to-day the obligation which we feel towards them for the kindness bestowed upon us.

Since these matters are freely dealt with in the special Volume of our Transactions to which the Report alludes, I will only now call your attention to the many expressions of gratitude, and to the many marks of goodwill, which have been conveyed to us by our guests of last summer.

There is nothing, so far as I can learn, of a startling nature in the Admiralty programme of the present year. Six new battleships are about to be laid down. Three of these are to be of the *Formidable*, or improved *Majestic* type; the designs of the remainder have not, I understand, as yet been decided upon.

Two years ago, when the designs of the *Canopus* type of battleship were made public, there was a chorus of rejoicing on the part of the advocates of moderate dimensions. We were told that to build these ships 2,000 tons smaller than the *Majestic* was a step in the right direction, that they were less expensive, and offered a smaller mark to torpedoes than the larger ships. I ventured to point out in my Address, at the time, that this reduction in displacement could not be obtained without sacrificing some portion of one, or all, of the qualities which we speak of as the desiderata in a ship of war—armament, propelling power, radius of action, and defensive armour.

In the *Canopus* class it was decided to reduce the thickness of the side armour considerably as compared with the *Majestic*. Our naval authorities had doubtless excellent reasons for following this policy at the time, and it is not necessary for us to particularise, or even surmise, what those reasons were; but, personally, I am thankful that we are returning to the heavier type of vessel, for in my judgment the increase in cost and displacement is more than compensated for by the enormous advantage which they obtain in defensive power. While on the subject of side armour it may be interesting to note that the Admiralty have taken a new departure in another class of vessel. For a good many years no cruisers with vertical side armour have been added to the British Navy. Last July it was announced that four such vessels were to be commenced. Some surprise was occasioned by this apparent deviation from our settled policy; but policy, as I need hardly remind you, is often dictated by

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physical considerations, and, till the recent improvements in armour were effected, it would not have been possible to put plates on the sides of swift cruisers of sufficient strength to adequately preserve them from the effects of shell fire. At the present moment this is no longer the case, and we need therefore feel no surprise at the Admiralty having decided to order the construction of these ships, which will have great speed, very considerable armament, and vertical protection to their vitals sufficient to resist any attack which they might be reasonably expected to encounter. I cannot leave this portion of my Address without expressing the regret which will, I am sure, be fully shared by all present, that the completion of the Admiralty programme of 1897-98 has been so grievously retarded by the deplorable labour troubles, which for seven months disorganised all engineering business in this country, and which were only terminated in January of this year.

In the Mercantile Marine, also, the year has not been marked by any striking departure in Naval Architecture. There are frequent rumours of new types and developments, but nothing has yet been reduced to practical shape.

The output of the shipbuilding yards of the United Kingdom amounted, according to Lloyd's Register, to about 952,000 tons gross (924,000 steam; 28,000 sail). In addition, warships to the extent of 95,000 tons displacement were launched, inclusive of those constructed at both Dockyards and private establishments.

The mercantile output of the year in the United Kingdom was less than that of 1896 by 207,000 tons, but was about equal to that of 1895. The decrease was mainly in steam tonnage. The construction of sailing vessels, which has been rapidly falling off since 1892, reached, last year, a lower point than any of which there is previous record. In 1892 sailing tonnage formed 24 per cent. of the output; while last year it formed only 3 per cent. of a considerably smaller total.

The warship tonnage launched at Dockyards and private establishments in 1897, likewise showed a very considerable decrease (68,000 tons) from the figures of the previous year. The tonnage launched for the British Navy was less by 51,000 tons than was the case in 1896.

About 25 per cent. of the mercantile output was built to the order of foreign and colonial shipowners in 1897, as compared with 30 per cent. in 1896, and 20 per cent. in 1895. Japan provided the largest amount of work for British shipbuilders, over 6 per cent. of the total output having been built for that country. Germany followed with over 3 per cent.

Of the warship output, 30 per cent. was for foreign account, Japan and Chili showing the largest totals.

I have already alluded to the effect of the great labour dispute on the realisation of the Admiralty programme; it has had a no less marked influence on the output for the Mercantile Marine. With the close of that unhappy struggle it is encouraging to find the shipbuilding and engineering industries with every prospect of full employment for some time to come. The returns show that the amount of tonnage (1,013,000 tons) now in hand in the United Kingdom is very large; and, as the quantity of sailing tonnage is unprecedentedly small, engineers as well as shipbuilders may be congratulated upon the present condition of affairs. It is generally understood, moreover, that the outlook as regards fresh orders is bright. Altogether, we may safely anticipate that, for both employers and employed, the immediate future will provide some reparation for the unfortunate losses of recent months.

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It is noticeable that the honour of producing the largest vessels of the year's output does not fall to this country but to Germany, our great rival in the shipbuilding industry. In that country were launched during 1897, the following three steamers of more than 12,000 tons each, viz.:—

Kaiser Wilhelm der Grosse	14,349	tons gross.
Kaiser Friedrich (approximate)	12,500	,, ,,
Pretoria (approximate)...	12,500	,, ,,

while the largest vessel launched in the United Kingdom was the *Cymric*, of 12,340 tons.

The credit for the construction of the largest sailing vessels of the year belongs, not to the United Kingdom, but to the United States of America and to France. In the United States have been built seven sailing barges, ranging from 3,180 to 3,800 tons, for trade on the Great Lakes, while the returns from France, where the shipbuilder and shipowner are alike stimulated by the operation of the bounty laws, show three sailing vessels of upwards of 3,000 tons each. In the United Kingdom no sailing vessel over 2,500 was built. It may be noted that the recent spurt in the construction of large sailing vessels in France appears to have partially spent itself. At the end of last year, less than 10,000 tons were in hand, as compared with 37,000 tons twelve months earlier.

It is striking to observe, from the statistics recently issued, how small an increase has taken place in the merchant navy of the United Kingdom during 1897.

During recent years we have been accustomed to large additions to its tonnage. After allowing for losses, sales to foreigners, &c., the net increase of the merchant navy of the United Kingdom, during the first nine years of the past decade, amounted on the average to 366,000 tons per annum. In comparison with these great totals it is remarkable to find that, during 1897, the net increase only reached the insignificant amount of 8,600 tons.

This great falling off is partly due, no doubt, to the strike, but it is also largely attributable to the great amount of tonnage which has been transferred to foreign and colonial owners during the year.

If we take the first half of the decade we find that, on the average 189,000 tons were then annually transferred from the United Kingdom; and if we take the second half of the decade we find the annual average stands at 344,000 tons. In 1897 even this latter average has been greatly exceeded, the enormous total of 446,000 tons having been sold abroad during the year. It will be understood that these figures are exclusive of new vessels built in this country to the order of foreign and colonial owners.

The foregoing figures indicate that it is now becoming customary for an amount of tonnage, equal to that of almost any other merchant navy, to be removed within, say, every two or three years, from the register of the United Kingdom on account of foreign sale. This tonnage, bought probably at moderate prices, and involving no large capital expenditure on the part of the purchasers, all tends to increase the severity of the competition with which the British shipowner has to contend.

This is a matter of grave importance. It is a sign of the times which should not escape the notice of those who are responsible for legislation. Whatever explanation might be afforded by an intimate knowledge of each separate transfer, it appears to be scarcely doubtful that the foreigner is often able to secure an adequate profit from vessels which his British competitor does not find sufficiently remunerative.

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From a national point of view, however, there is one consolatory aspect of this subject. In the main, the vessels which are sold abroad are found, upon investigation, to be of not very recent construction. For instance, nearly three-fourths of the vessels transferred from the United Kingdom during the last two years were built before 1885. This fact, taken in conjunction with the largely increased amount of steam tonnage which is now annually broken up, suggests that the British shipowner is generally alive to the necessity of keeping his fleet abreast of the times.

This view is supported by the circumstances that the gross addition of newly built steamers to the Register of the United Kingdom during the last decade has exceeded 7,300,000 tons. These figures represent nearly three-fourths of the steam tonnage at present owned in the country. Some allowances must, no doubt, be made on account of losses and sales to foreigners among these recently built vessels; but, after making all needful deductions, we can congratulate ourselves that the greater part of the vast British Mercantile Marine is of efficient modern construction.

I now turn to the subject of the papers to be read at the Meetings, and can congratulate you on the fulness of the programme and on the interesting character of the subjects which you will have the opportunity of discussing. One of the most striking features of the programme is the number of papers communicated to us by our friends from abroad. No less than seven out of a total of seventeen have their origin outside this country. I think the Institution is to be heartily felicitated on this fact, proving, as it does, that we are able to enlist the sympathy and co-operation of Naval Architects in all parts of the world. The United States, Germany, Austria, Russia, and Norway, each contribute to our instruction on this occasion. What more convincing proof could we have of the excellent results to the Profession which have attended our policy of visiting our foreign friends in their own countries, and of inviting them to honour us by their presence here?

I thank you, gentlemen, for the indulgence with which you have heard me to-day, and I will now conclude by formally moving the adoption of the Report.

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RESULT OF THE BALLOT FOR THE ELECTION OF MEMBERS AND ASSOCIATE MEMBERS OF COUNCIL.

Before the reading of Professor Hele-Shaw's paper on Wednesday, March 30, the Scrutineers appointed to examine the ballot papers for the election of the new Council presented the following report:—

Society of Arts, John Street, Adelphi, London, W.C.,
March 30, 1898.

To the Right Hon. the EARL OF HOPETOUN, G.C.M.G., *President, Institution of Naval Architects.*

MY LORD,—We hereby certify that the following gentlemen have been duly elected:—

As Members of Council—

Mr. Alexander Adamson.	Sir William Gray.
Mr. S. W. Barnaby.	Mr. R. H. Humphrys.
Mr. H. E. Deadman.	Mr. J. R. Thomson.

As Associate Members of Council—

Mr. T. H. Ismay.	Mr. James Riley.

We are, my Lord,

Your obedient servants,

(Signed) J. H. BILES, Member of Council.
J. WARD, Member.
(Scrutineers).

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RECENT TRIALS OF THE CRUISER *DIADEM*.

By Sir JOHN DURSTON, K.C.B., R.N., Engineer-in-Chief of H.M. Navy, Vice-President.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 30, 1898; the Right Hon. the Earl of HOPETOUN, G.C.M.G., President, in the Chair.]

THE author had the honour in April last to submit to the Institution some notes on the trials of the cruisers *Powerful* and *Terrible*, the first ships in our Navy of large power fitted with water-tube boilers of the Belleville or large tube type, and the present paper respecting the trials of the cruiser *Diadem* is submitted as a supplement or a continuation of those notes.

While the boilers of the first four vessels of the *Diadem* class were under construction, trials at Paris of Belleville boilers fitted with economisers showed considerable advantages over the *Powerful* type of boiler, in economy of fuel, less tendency to production of smoke, and lower funnel temperatures. Consequently it was decided to alter the boilers of the vessels of this class by reducing the number of generator tubes, and fitting economisers as shown in Plate I., which gives longitudinal sections of the boilers of the *Powerful* and *Diadem*, and also a transverse view showing two boilers of the last-named ship, one being shown in section and the other in elevation.

Comparing the section of the boilers of the *Diadem* with that of the *Powerful* type of boiler, it will be seen that the number of rows of $4\frac{1}{2}$ in. generating tubes in each element has been reduced from ten to seven, while over the generating tubes there is a space provided corresponding to that of the combustion chamber in an ordinary return tube cylindrical boiler, and above this space is situated another nest of tubes of smaller ($2\frac{3}{4}$ in.) diameter, and seven rows in height, forming the economiser. The furnace air-blowing engines supply jets of air to this space as well as into the furnaces below. The feed water is pumped into the lower part of the economiser, traverses to the top of its elements, and from thence it is led to the steam collector for feeding the generating tubes.

The advantages of this arrangement are that the combustion is more effectually completed, the escaping funnel gases are of a much lower temperature, firing does not require so much attention, and a considerable economy in fuel is obtained.

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The Table following shows the disposition of heating surfaces and the total weights in representative eight-element boilers in the *Powerful* and *Diadem* respectively.

ONE BOILER.

Ship.	Number of Elements.		Heating Surface.			Fire Grate.	Weight of Boiler, with Furnace Fittings, Casings, Lagging, and Mountings complete.	Weight of Water.	Total Weight.
	Generator.	Economiser.	Generator.	Economiser.	Total.				
			Sq. Ft.	Sq. Ft.	Sq. Ft.	Sq. Ft.	Tons.	Tons.	Tons.
Powerful ...	8	Nil.	1,420	—	1,420	49	17·4	1·1	18·5
Diadem ...	8	6	995	355	1,350	49	16·7	1·3	18

It will be observed that there is a slight increase in weight of water due to the economiser, but this does not interfere with the tactical advantage possessed by the boiler in raising steam quickly, for the amount of water in the generator portion is reduced.

The machinery of the *Diadem* class is designed to attain a maximum power of 16,500 I.H.P., and a continuous sea-going power of 12,500 I.H.P. for as long as the coal lasts.

The specified trials were :—

(1) An eight hours' trial at 16,500 I.H.P. with all boilers in use ;

(2) A thirty hours' trial at 12,500 I.H.P. with all boilers in use ; and

(3) A thirty hours' trial at 3,300 I.H.P. with the number of boilers at discretion of contractor. (Only the after set of eight boilers, or 27 per cent. of the total boiler capacity, was actually used.)

The maximum pressure at which the engines were specified to work was 250 lbs. per square inch, with a boiler pressure of 300 lbs., an increase of 40 lbs. beyond that specified for the *Powerful* and *Terrible*.

The engines are of a similar type to those of the *Powerful* and *Terrible*, two low-pressure cylinders being fitted, *i.e.*, the engines are of the four-cylinder triple-expansion type.

The diameters of the cylinders are as follow :—

High-pressure		34 inches.
Intermediate-pressure		55½ ,,
Two low-pressure	each	64 ,,

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The stroke is 4 ft., with a design cut off in the high-pressure cylinder of 73 per cent.

The ratio of low-pressure to high-pressure cylinder volume is 7·08.

Allowing for a clearance in the high-pressure cylinder of 25 per cent., and in the low-pressure cylinder of 15 per cent., the designed real ratio of expansion at full power was about 8·3.

The cylinders are arranged as in the *Powerful*, with the high-pressure cylinder forward, and the two low-pressure cylinders aft. The two low-pressure cranks are opposite each other, and the high-pressure and intermediate-pressure cranks also opposite each other, but at right angles to the low-pressure cranks.

The high-pressure and intermediate-pressure cylinders are arranged with centres as close together as possible, the valve casings of each of these two cylinders being, for this purpose, placed away from the other cylinder. The two low-pressure cylinders are similarly arranged, the moments of the forces, therefore, causing vibration are relatively small.

It may be stated that, throughout the whole range of power and revolutions developed in these trials, the vibration was inappreciable.

There are no balance weights nor any special means of reducing vibration beyond the arrangement of cranks and disposition of cylinders.

All the cylinders are steam jacketed; those of the intermediate-pressure and low-pressure cylinders, only, were used on the trials, the pressure maintained in these jackets being regulated to approximately equal their respective receiver pressures.

The boilers are thirty in number, twenty of them containing eight generator elements and six economiser elements, six having seven generator elements and six economiser elements, and the remaining four containing nine generator elements and seven economiser elements; this distribution being dependent upon the width of stokeholds available in the various sections of the ship.

The boilers are arranged in four compartments with tubes fore and aft, eight in each of the three after and six in the forward one, placed back to back in each compartment. The gases are led into four funnels, and the uptake leads from the boilers are practically vertical.

Each boiler compartment has a separate main steam pipe and feed system, the four main steam pipes being carried to the forward bulkhead of engine-room, with the usual stop-valve to each pipe at the bulkhead.

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The total heating surface of the boilers, as originally designed, was 42,270 sq. ft., or 2·56 sq. ft. per I.H.P. After the boilers were modified the heating surface in the generator portion was reduced to 29,600 sq. ft., or 1·8 sq. ft. per I.H.P.; while in the economisers an addition was made of 10,950 sq. ft., or ·66 sq. ft. per I.H.P., making a total surface of 40,550 sq. ft., or 2·46 sq. ft. per maximum specified indicated horse-power.

There are four main feed pumps and four auxiliary feed pumps; but, unlike the *Powerful* and *Terrible*, the main feed pumps and separators are placed in the boiler compartments instead of in the engine-rooms.

The usual stokehold fans, necessary to ensure a constant supply of air from the upper deck in all circumstances, and air-blowing engines for the purpose of supplying air in jets to mix the furnace and combustion chamber gases and assist the combustion, are fitted.

Table A gives the detailed results of all the trials carried out, and average sets of Indicator Diagrams are shown on Plates II. to V.

The first trial was the contract thirty hours' trial at 3,300 I.H.P., *i.e.*, one-fifth the designed maximum power, and the results are given in the first line of the Table.

Eight boilers with eight elements each out of the thirty boilers were used, the mean power being 3,318, the coal consumption per indicated horse-power per hour being 2·18 or 18·4 lbs. per square foot of grate per hour.

It should be observed that during this and all subsequent trials the necessary auxiliary machinery was at work, and the coal consumption includes the expenditure for this purpose, no deduction having been made on this account and no additions having been made to the indicated horse-power shown by the main engines. The coal used, therefore, includes that for the auxiliary engines connected with the main engines—the evaporating apparatus, steering engine, and a 600 ampère dynamo supplying electric light to the whole ship.

The second trial was the contract thirty hours at 12,500 I.H.P., *i.e.*, about 75 per cent. of the maximum specified power, with all boilers in use. This trial was carried out in a very satisfactory manner, the power realised being 12,813, while the coal consumption, taken as defined in the contract, for twenty-four consecutive hours, was 1·59 lbs. per I.H.P., or 13·9 lbs. per square foot of grate per hour. During this trial three runs were made over the measured long-distance course (23 nautical miles) between Rame Head and Dodman Point, when, with no wind and a calm sea, a mean speed of 19·79 knots was realised.

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To face page 4.]

Name of Ship.	Description of Trial.	Distribute ses- e at ease the P. ain- er.	Total Ratio of Expansion on Trial.	Coal used per hour.		Propellers.				Speed on Measured Mile or Deep Sea Course.	Date of Trial.
				Per sq. ft. of Grate.	Per I.H.P.	Diameter.	Pitch.	Slip Per Cent.	Expanded Blade Area of Each.		
		ns.		lbs.	lbs.	ft. ins.	ft. ins.		sq. ft.	knots.	
Diadem	Contractors' 30 hours' coal consumption	5·4	15·7	18·4	2·18	16 9	22 11⅛	16·4	58	12·74 (*a*)	18th & 19th January
Do.	Contractors' 30 hours' coal consumption	2	10·3	13·9	1·59	,,	,,	20·3	,,	19·79 (*b*)	21st & 22nd January
Do.	Contractors' 8 hours' full power ..	5	8·7	20·8	1·76	,,	,,	23·3 *22·8*	,,	20·6 (*c*) *20·72* (*e*)	26th January
Do.	4 hours' trial	5·8	8·7	27·1	1·95	,,	,,	..	,,	Not taken.	29th January
Do.	15 hours' trial	5·9	15·7	19·6	2·35(*d*)	,,	,,	..	,,	Not taken.	7th February
Do.	15 hours' trial	3·5	10·3	17·6	1·94(*d*)	,,	,,	..	,,	Not taken.	8th February
Do.	30 hours' trial	2	10·3	21·2	1·88(*d*)	,,	,,	..	,,	Not taken.	10th & 11th February
Recent representative battleship	30 hours' coal consumption	3	..	13·8	1·82						
Do.	8 hours' natural draught	1·7	..	29·5	2·3						
Do.	4 hours' full power	4·0	..	Not taken.	..						
Recent representative 2nd-class cruiser ..	30 hours' coal consumption	7·9	..	12·6	1·6						
Do.	8 hours' natural draught	1·2	..	28·8	2·2						
Do.	4 hours' full power	4·0	..	Not taken.	..						

(*a*) At 67 Fires cleaned practically every 8 hours.

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The boilers generated steam freely, the stokeholds being open and the fans not in use.

The third contract trial, *i.e.*, at 16,500 I.H.P. for eight hours, with all boilers in use, was carried out on January 26, when a mean collective indicated horse-power of 17,262 was obtained with open stokeholds and the ventilating fans running slowly.

The coal consumption was 1·76 lbs. per indicated horse-power, or 20·8 lbs. per square foot of grate per hour. The speed of the vessel was again tested by three runs over the long-distance course between Rame Head and the Dodman: 20·6 knots was the mean of the three runs; but, as the first two runs were made on slack water, and the third against a tide, there is no doubt that the true speed is higher than this figure. The mean of the first two runs was 20·72 knots.

In addition to the preceding contract trials the following experimental trials were carried out:—

In the first place it was desired to test the capability of these modified boilers when being pressed beyond the amount necessary to obtain the specified maximum power. For this purpose a trial of four hours was made on January 29 with the three after stokeholds only, the boiler power in which amounted to 78 per cent. of the total boiler power of the ship, developing about the specified maximum power.

On this trial the horse-power realised was 15,861, the coal consumed per indicated horse-power per hour being 1·95 lbs., and the coal burnt per square foot of grate 27·1 lbs. per hour. The boilers generated steam for this power satisfactorily, but accelerated draught was necessary to the extent of $\frac{3}{10}$ in. of air pressure in the stokeholds.

With a higher air pressure, no doubt the proportion of boilers used would have generated a still higher power, but it was considered undesirable to press them further beyond the contract amount.

It will be observed that, on this trial, the combined heating surface in the generators and economisers was at the rate of about 2 sq. ft. per I.H.P.

On February 10 and 11 similar trials were made with the same boilers, *i.e.*, 78 per cent. of the total boiler-surface, to test their capacity for maintaining for long periods a higher power than contracted for, and it was endeavoured to obtain with this proportion of boiler power the full continuous steaming power, *i.e.*, 75 per cent. of maximum power specified to be obtained with the whole of the boilers at work. This was successfully realised, and, with open stokeholds, 12,852 I.H.P. was maintained for thirty hours, the coal consumption per I.H.P. being 1·88 lbs. per hour, or 21·2 lbs. per square foot of grate.

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On this trial the coal, although hand-picked, was of an inferior quality as regards quantity of clinker, which necessitated the fires being cleaned much oftener than usual. They were completely cleaned each eight hours, and this largely accounts for the difference in coal consumption between this trial and the corresponding one with the whole of the boilers at work. A certain increase would, however, be expected, due to the higher rate of combustion at which the boilers were being worked.

Another trial was made on February 7 of fifteen hours' duration under exactly the same circumstances as the first contract trial, with a view of confirming, or otherwise, the coal consumption then shown; but, unfortunately, the coal in the bunkers on this trial was much inferior, and produced a much larger amount of clinker: 3,266 I.H.P. was obtained, and the coal consumption was 2·35 lbs. per I.H.P., as against the 2·18 obtained on the original trial, and the difference between these two figures may be regarded as entirely due to the quality of the coal, and to the constant cleaning and clinkering necessary. On the succeeding ships of the class, two of which will probably be tried within the next three months, this question of consumption at one-fifth power will be further tested. With a larger proportion of boilers in use for this low power, say, twelve instead of eight, better results may be obtained.

A further trial was made of fifteen hours' duration on February 8, to compare the powers developed in the engines, using 150 lbs. steam pressure, with that obtainable at 250 lbs. pressure, the cut-off in the cylinders being the same.

The trial selected for comparison was the second contract trial, and the links were therefore set at the same position as they were on the trial of January 21, when an indicated horse-power of 12,813 was obtained.

The mean power at this reduced pressure was 7,119, the revolutions being 89·5 as against the 107·6 on the original trial. The power was therefore about 55 per cent. of that obtained with 250 lbs. pressure. The coal consumption was 1·94 lbs. per indicated horse-power per hour. As the same inferior quality of coal as regards clinker was used, and a higher rate of combustion was employed, this consumption is, no doubt, greater than would otherwise have been the case.

On all the contract and experimental trials the pressure of steam in the supply pipes to the auxiliary machinery was restricted by reducing valves to about 150 lbs. per square inch.

On the trials of the *Powerful* and *Terrible* it was found particularly necessary to regulate the firing, while on the trials of the *Diadem* with the modified type of boiler such close attention, although beneficial, was found to be not so necessary, and more latitude in thickness and level of fire is permissible.

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A comparison of weights per indicated horse-power in recent designs, similar to that given last year in the case of the *Powerful*, is as follows :—

TABLE B.

SHIP.	Indicated Horse-power.	A Weight of Machinery in Eng. Rooms. Tons.	I.H.P. per ton of A.	B Weight of Propellers, &c. Tons.	I.H.P. per ton of B.	C Total Weight of Main Engines, propellers &c. = A + B Tons.	I.H.P. per ton of C.	D Weight of Boilers and Fittings. Tons.	I.H.P. per ton of D.	E Total Weight of Main Machinery and Boilers. = A + B + D Tons.	I.H.P. per ton of E.
Average of nine recent battleships..	10,000 (N.D.)	445·01	22·47	98·17	101·86	543·18	18·41	719·31	13·92	1262·49	7·92
	12,000 (F.D.)		26·96		122·23		22·092		16·706		9·505
Powerful	25,000	789·5	31·66	192·72	129·7	982·2	25·45	1162·05	21·51	2144·27	11·7
Percentage of increase over battleships	Compared with N.D.								54·52		
	Compared with F.D.		17·433		6·126		15·20		28·75		
Diadem	16,500	576·45	28·62	111·9	147·45	688·35	23·97	748·4	22·05	1436·75	11·48
Percentage of increase over battleships	Compared with N.D.								58·405		
	Compared with F.D.		6·16		20·63		8·501		31·988		20·778

The *Diadem* and *Powerful* are compared in Table B. with nine recent battleships with cylindrical boilers and 155 lbs. steam pressure.

It will be seen that the percentage of increase of indicated horse-power per ton weight of boilers and fittings, comparing the full power of the *Diadem* with the natural draught power of the nine battleships, is 58·4 per cent., while in the *Powerful* the corresponding figure is 54·5 per cent.

Comparing the *Diadem* and the *Powerful*, the specified power in the latter was 31·66 I.H.P. per ton of machinery weights in engine-room, while in the former it was 28·62, the heavier weight of the *Diadem* engines being largely accounted for by the larger ratio of cylinders fitted, *i.e.*, a ratio of 7 to 1 against 5·7 to 1.

A series of trials in connection with the auxiliary machinery, which were carried out in the vessel while in basin, preliminary to these speed and power trials taking place, will now be referred to.

The coal consumption for auxiliary purposes, *i.e.*, for purposes not required simply for propelling the vessel, as reported in some recent ships was considered abnormally high, and the opportunity was taken to test the quantities of steam or coal required

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for such purposes only, by a series of trials with the engines at rest and the ship in the basin.

These trials were made with two boilers in use, each trial being of eight hours' duration, and the amount of coal burned was measured when various combinations of auxiliary engines were at work. For example, trials were made with certain auxiliary engines in use, and also the electric light installation and distilling plant, and the trials were repeated with electric light engines stopped, so that, by a process of subtraction, the amount of coal used by the electric light installation was ascertained.

The figures on Table C. give a summary of the results obtained. They are not uniformly consistent, and, in considering some of the figures, allowance must be made for the inevitable variation in stoking and possible differences due to variations in the conditions of the fires at the beginning and end of each trial, and to the small quantities of coal burnt per square foot of grate.

The figure 3·75 tons in trial M, even assuming it may be slightly under-estimated owing to varying conditions above mentioned, indicates a high economical performance in both the engines and boilers in use, particularly as deductions must be made for coal expended in simply maintaining pressure in the large system of pipes in use (suggested by trials C and D).

It will be seen by comparing trials G with I, and H with J, that the length of steam pipe in use has an important bearing on the coal consumption. The conditions in G and H were the same as in I and J respectively, except that two of the extreme after boilers were in use in the latter trials, and two of the extreme forward boilers in trials G and H. A saving of 20 per cent. to 30 per cent. of the total coal used was effected by the use of the after boilers, *i.e.*, those with the shortest steam pipes

A comparison of trials A and G, in which latter a saving of 15 per cent. of coal is effected over trial A by using a lower pressure of steam, indicates that it is not desirable to use the higher pressures of steam which can be carried in the boilers when working the auxiliary engines, and this lower pressure of steam was used on the subsequent trials under way. The main engines are designed to work at the high grades of expansion necessary for obtaining the increased economy to which the high-pressure steam lends itself; but, as the degree of expansion in many of the auxiliary engines is either non-existent or very limited, particularly in such engines as feed engines, blowing engines, and auxiliary circulating engines—which are simple engines with very late cut-off—no advantage is obtained by increasing the pressure beyond that which is absolutely necessary to obtain the full work out of the engines in use. In the present case that pressure is about 155 lbs. in the electric light

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engines, and 170 lbs. in the refrigerator engines, both these engines having compound cylinders.

Assuming a water consumption for the electric light engine of 30 lbs. per E.H.P. per hour and an E.H.P. of 64, with an evaporation in the boiler of 9 lbs. of water per pound of coal, the coal equivalent of the electric light engine works out to 2·4 tons per day.

The difference between C and A gives 7·8 tons as the coal expended on electric light and distilling, and deducting 2·4 for electric light we have 5·4 tons for making 59·69 tons of water, or 11·1 tons of water per ton of coal.

Again, the difference between C and B = 4 tons, which was expended in distilling 41 tons of water, or 10·25 tons of water per ton of coal, a result agreeing well with the figure previously given, the difference pointing, probably, to a slight reduction in efficiency due to the scale formed on evaporator coils.

In conclusion, it is submitted the trials carried out in the *Diadem*, which have been neither few in number nor, generally, short in duration, have shown that the engines and boilers are economical and efficient for warship service, and the fitting of the economiser to the boilers has been attended with beneficial results.

I would also beg to acknowledge the services and assistance rendered by my brother officers in this work, and the ready manner in which Monsieur Belleville has placed at our disposal the important improvement he has made in adding the economiser to this type of boiler.

DISCUSSION.

Mr. A. E. Seaton (Member of Council): My Lord and Gentlemen, there is no doubt we are very much indebted to Sir John Durston for coming forward in this frank and candid manner to give us the benefit of the recent experiences with the Belleville boiler. The subject, as all of us know who are assembled here, has been in the past a very prickly one, and one that has very often led to acrimonious discussion. On the part of Sir John we have never witnessed anything of the kind. He has always been most free and liberal in giving us information, and receiving the severest of criticisms perfectly kindly and good-humouredly. I cannot help, however, alluding to one point in his paper, which I think is a most important one. Of course, as the paper is particularly one on boilers, perhaps he has not touched upon it as extensively and seriously as I think he might have done, and that is, the enormous consumption in the auxiliary engines of a warship. We find in the Mercantile Marine, with the same style of auxiliary machinery, a smaller wastefulness. The fashion in late years has been for direct working pumps—or, perhaps, I had better call it by the name of its original inventor—the Weir system, and with engines afloat it is undoubtedly a most beautiful one.

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No one who has had experience with the Weir pump can fail to admit that, as an instrument for supplying water to the boilers with the least amount of care and anxiety, it is unequalled; but I am afraid to say it is unequalled in another respect, and that is the consumption of steam. You cannot eat your cake and have it too. If you will have a pump which is very efficient as a pump, as a supplier of water to the boilers, and, at the same time, a pump that does not give the engineers, or anybody concerned, the least anxiety, you must be prepared to pay something for it; and you must not lay the blame to something else. Unfortunately, I do not say here, but in another assembly, it is not an uncommon thing to lay the failure of every instrument in the Navy down to the unfortunate Belleville boiler, and, in this respect, the pumps are no exception. We have recently had trials with the *Argonaut* cruiser fitted with the Belleville boiler, but without the economisers. The good working of the boilers was unquestioned, and the confidence with which the men worked the boilers is, I think, also unequalled in the annals of steam engineering. The free and easy way with which both the engineers and the firemen treat these boilers is something almost to marvel at; but, in spite of having a very successful trial, and one conducted practically with no hitch, the fuel consumption, for which we as contractors had to pay, was a little bit alarming to us. Further investigations were made at the expense of the Admiralty, and it was discovered that the one great source of loss was in the auxiliary machinery; for, not only are the auxiliary feed pumps but the blowing engines, the auxiliary pumps which pump the bilges and supply water to the deck, which are all of the same type, all great users of steam, but, at the same time, they work remarkably well. Now, I think it would be very well worth the while of some engineer members of this Institution if they would turn their minds to the invention of a pump which will do its work as a feed pump satisfactorily, and in all respects with the same ease to the mind of the engineers as the Weir system; but that, by its compounding or by some other arrangement, the consumption of steam shall not be nearly so heavy. There is another point to which, perhaps, attention should be called, and it is becoming a serious one; that is, the very great loss through radiation from the imperfect nature of the material that we now put on boilers and pipes. The old days of felt are practically gone. We have to resort to other materials, and, though in themselves they are very good, the difficulty is so to apply them that they should do the duty expected of them without loss from other causes; for instance, the various asbestos compositions are exceedingly good as non-conductors of heat, and we can, of course, apply them, more or less successfully, to pipes and other hot surfaces, but they very soon begin to lose their efficiency from the incomplete attachment to the hot surface, and also from the metallic bodies used to hold them in place becoming very quickly conductors of heat. We have been recently scheming some method of coating the pipes and casings of these boilers to avoid this, but it is a most difficult thing to get perfect insulation, and it is astonishing how much heat will pass away through a very small section of metal which is in direct contact with either the pipe or boiler casing. There is no doubt that these two things combine to make the very high pressure system now used in the Navy and Mercantile Marine a somewhat costly one; but I do not think it should deter either the steamship owner or his advisers, any more than it deters Sir John Durston and his assistants, from pursuing the course of perfecting that which we know will eventually give unmeasured success. The steam pressures that are best used in water-tube boilers are, naturally, very high. The reducing valve which, perhaps, is rather a steadier of steam supply and a controller of it than a mere reducer, of course helps matters somewhat; but, at the same time, it tends to super-heat the steam, and makes the temperature of that issuing from the reducing valve almost as high as the steam before it reaches it. Now, if we are to have the advantage of this hot steam, and practically dry steam, we must follow up very closely the methods for controlling the loss and preventing it—not merely turn our

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back on the thing and say it is a failure, and it is no use going on with it. There is no question in my mind that the economiser was the great thing needed to make the Belleville boiler a practical success. Anyone who has had experience with the original design knows that the heat at the funnel base was not only high, but apt to be irregular, and that the flaming at the funnel was notorious with that class of boiler. The introduction of the feed into the upper casing has, as Sir John Durston has very clearly shown us, cured both evils, and I have no doubt that, if the *Powerful* and the other vessels now fitted with the ordinary Belleville boiler can have some modification of the economiser or feed heater, the consumption of fuel in them would be proportionately reduced to that of the *Diadem*. The question of feed heating, of course, has always had an attraction to engineers, but I do not think, until recently, sufficient attention has been paid to the fact that the efficiency of the heating surface of either the feed heater or the boiler must depend on differences of temperature. I had the pleasure last year of witnessing an experiment with Mr. Yarrow's boiler, about which he has been good enough to give us a paper this year. The very great gain which could be obtained by paying a little attention to that fact was impressed upon my mind.

Mr. R. W. Allen (Member): My Lord and Gentlemen, I did not intend to make any remarks on this paper, but, as Sir John Durston has mentioned the auxiliary machinery in H.M.S. *Diadem*, I trust I may be allowed to say a few words, as my firm designed and constructed most of the auxiliary engines. Since the trials have been carried out on that ship I thought it would be of interest to the Institution, and to Sir John Durston, to make some trials at our works with the auxiliary machinery we are constructing. Several members have pointed out that little attention has been given of late years to the steam consumption of auxiliary engines. I may mention that in 1884 (I think that was the year when the first electric-light engine and dynamo was fitted in Her Majesty's service), the steam consumption of the engine and dynamo was 140 lbs. of water per electrical horse-power per hour. During the present year we have constructed the electric light machinery for H.M.S. *Amphitrite*, and on the official trial the steam consumption of each of the electric light engines, when working non-condensing for the above ship, was 27 lbs. of water per electrical horse-power. I think this comparison will show that some attention has been paid to the economy of electric light machinery. With regard to the main circulating pumping engines, I think they come next in size amongst the auxiliary machinery attending the main engines. In the *Diadem* each of the four main circulating pumping engines is capable of developing 80 H.P. No doubt we could reduce the steam consumption of these engines, if the power of the engines was reduced; but the specification states that we are to pump out the bilge with the same engine as is used for circulating, and, when such large power has to be allowed for in the cylinder capacity, it is difficult, and in fact impossible, to obtain economical results when working circulating, as only about one-fifth part of the original power is required. In regard to the fan engines, we have made many hundreds of tests of every kind, and we find that ordinary single-cylinder fan engines consume about 50 lbs. of steam per indicated horse-power, having a cut-off of 40 per cent. of the stroke. Most of the specifications state that the fans and engines, at the official trial at the maker's works, are to run "in the open" (that is, without a casing to the fan) at a much higher speed than in actual practice. To effect this you have to allow a large cylinder area, and when the fan is running with a casing at a lower speed than the test speed, the cylinder is often 50 per cent. too large, on account of the fan requiring much less power to drive it when fitted in a case. If we could proportion the size of the cylinders of all the auxiliary engines more to the actual work they have to perform in practice, and also arrange an earlier cut-off, I am sure a great saving in the steam consumption throughout the

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auxiliary engines would be gained. With respect to the furnace air-blowing engines, I think the results are the most startling we have found out lately. Take, for instance, those we are now testing for the third-class cruisers. Six are fitted in each ship. We find that, at the lowest speed at which the engines would run, viz., thirty-eight revolutions, the steam consumption per indicated horse-power is 200 lbs., while the indicated horse-power is only 3; and the maximum horse-power of these engines, when working at 30 lbs. pressure, is 35; and the steam consumption per indicated horse-power when working at full power is 50 lbs. Now this engine was taken out for 30 lbs. pressure, but it looks to me that the efficiency of the pump would be greater if reduced to 15 lbs., when the total steam consumption would be reduced by nearly 50 per cent. A great saving in the total consumption would, no doubt, be effected when working at 15 lbs. pressure of air instead of 30 lbs. The total steam consumption of each engine when working at full load with 15 lbs. of air is 1,000 lbs. per hour, or 6,000 for six blowing engines per ship. Mr. Seaton mentioned the reducing valves as fitted on board ship. I think it would be well if we would persevere in regard to these fittings. We have made several trials lately, and find that with 220 lbs. of steam we obtain the same steam consumption, working direct from the boiler without the reducing valve, as with it, fitted with 150 lbs. of steam. These figures show that a reducing valve has some effect, and keeps back the particles of water which otherwise pass over the steam to the engines. I think these remarks are all I wish to make.

Mr. J. Macfarlane Gray (Member of Council): My Lord, I did not intend to have said anything on this excellent paper, but Mr. Seaton's remarks suggest to me that I might say something about the economiser. He has quoted Mr. Yarrow as saying that the efficiency of heating surface depends altogether upon the difference of temperature between the heating gases and the water that receives the heat. I thought so, too, for many years, and I used to laugh at the idea some people had that there was thermal economy in heating feed-water with sharp steam. I am now forced to admit that I have been in error, and that there is actual thermal economy in so heating by steam, and this has proved to me that efficiency does not depend entirely upon the difference of temperatures. In the economisers now described we have the feed heated, as it were, in a separate boiler. This is the year 1898, and it is therefore just two hundred years since there was in 1698 a patent granted to Captain Savery, a London shipmaster, for the first commercially successful steam boiler and engine, and it has escaped attention all these years that that boiler was, like this improved Belleville boiler, made in two pieces, one boiler to heat the water up to the temperature of the steam, and the other boiler to evaporate it. To this separation of heating and evaporating I think we are bound to return. This has been proved by experiments made with the thermal storage plant of Mr. Druitt Halpin. In that system water is heated during the day and stored in a separate tank to be used at night, in an electric light installation—heating the water while there is no other use for the boilers. To satisfy inquirers regarding the supposed loss of heat on this plan, he set his assistants to make an economy trial, to compare the evaporative efficiency of the fuel, when feeding direct into the boiler from the hot well, and when feeding into the storage tank, and there heating it up to, practically, steam temperature by free admission of boiler steam, at which temperature it then entered the boiler. Mr. Halpin expected that there would be a small loss by the more circuitous method. To his astonishment his assistant reported that there was not only no loss, but actually a 16 per cent. gain. "Oh, nonsense! Get away with you! There is some mistake; we must do it over again." They did it over again, and again it came out 16 per cent. economy. They could not understand it. Mr. Halpin applied to Professor Unwin, who also conducted independent experiments at Margate, and he in two

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experiments obtained 19 per cent. economy. They were unable to account for the result. It came before me, and, having satisfied myself that the experiments had been carefully made and accurately summarised, I came to the conclusion that the economy realised was due to an increased efficiency of the heating surface, whereby the temperature of the products of combustion had been still further reduced. The increased efficiency I attribute to increased motivity of the water at the heating surfaces. To account for this better circulation, the water is fed in at the temperature of the steam, then the slightest communication of heat to it must cause a proportionate particle of the water to become steam, and the enormous difference in specific gravity between water and steam causes a rapid ascent of the steam spherules. On the other hand, if the water is supplied at 100° lower temperature than the steam, that water has only the motivity of fluid circulation carried on by temperature differences of specific gravity until a considerable part of it attains the temperature of the steam. We all know the marked difference there is between the efficiency of the heating surface when the water is moving rapidly over it and when the water is standing still. If, in these experiments, either 16 or 19 per cent. advantage in economy was actually obtained, what we must return to is that, in a boiler no heat ought to be ever transmitted through a metallic heating surface but the latent heat. The elevation of temperature should be always accomplished wholly by steam contact. Applying this deduction to the economisers in Sir John Durston's paper, I think they ought to prove doubly effective, because they not only pick up what would otherwise be waste heat, but they also, as I have tried to explain, increase the efficiency of the heating surface of the boiler proper. I ought to state that I have been told that Professor Elliot, of Cardiff, wrote a paper some years ago attributing the economy of steam-heated feed to increased efficiency of the boiler heating surface, and Mr. Seaton tells me he also pointed this out some years ago. I have been now telling you how I think this increased motivity is produced, and to that I attribute the increased efficiency of the heating surface and the, thereby, enhanced economy.

Mr. Frederick Sawyer (Member): My Lord, the only point on which I wish to make any observation is with regard to the distilling apparatus, which forms an important portion of the auxiliary machinery of a battleship. I read here that eleven tons of distilled water are produced by the consumption of one ton of coal, but I wish to say that it is perfectly easy to obtain a much greater quantity of water than that from the consumption of a ton of coal. In the works of which I recently had charge I constructed for Sir Alexander Rendel an evaporator which is now at work in Uganda, which was of sextuple effect, and which evaporated thirty-five tons of water per ton of coal. It is true that the increase in weight, and possibly in bulk, would be a disadvantage on board a cruiser or battleship; but, on the other hand, if you consider that you might obtain three times the quantity of distilled water per ton of coal used, and that this apparatus is frequently, if not continuously at work, I venture to say that the saving in coal, and consequently in weight and space, on a very short cruise would make up for the extra weight of apparatus put on board, and the extra space which would be occupied. With regard to Mr. Macfarlane Gray's remarks, I might say that I have for years, at the Mirrlees, Watson & Yaryan Company's works in Glasgow, made evaporating apparatus, every vessel of which was fitted with a heater, so that, as he says, there were evaporators, and there were heaters; thus, whatever the temperature of the evaporator was—and that depended of course, upon the vacuum maintained—the water or the liquid, whatever it was, that entered into this evaporator was immediately evaporated; or rather, the evaporator was not troubled to do any heating—it only had to supply the extra heat which was necessary at once to turn the liquid into vapour. I think, my Lord, that is all I have to say.

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Mr. A. F. Yarrow (Vice-President): My Lord, there is only one point on which I would like to make any remark. Owing to the large loss through the auxiliary machinery, it is customary sometimes to pass the exhaust from these engines into the reservoir of the low-pressure cylinder. That, at one operation, compounds all the engines with little increased complication. I should very much like to know whether there is any insuperable difficulty in that being carried out in a large warship.

Sir John Durston, K.C.B., R.N. (Vice-President): My Lord and Gentlemen, the object of relating these experiments which we have recently made on auxiliary machinery, has been, to a certain extent, fulfilled by the remarks made by the gentlemen present. I should have liked to have heard and have gathered the experience of a larger number. As Mr. Allen has said, we know the water consumption of electric lighting engines, for electrical horse-power has been closely watched for many years, with, as he states, the very satisfactory reduction from 140 lbs. down to 27 lbs. Of course, as you can see, the electric light engine we can easily compound. It will do its work as a compound engine as well as a simple one, and the same thing applies to the refrigerator engines on board ship. They are doing constant work; but, when you come to the feed pumps and circulating engines, fan engines and air-blowing engines, it becomes a question of space, and, if we think of the steering engine, then it becomes a question of efficiency, because the higher you compound an engine the less handy it is to do its work. In reply to Mr. Seaton, I might say that we are continuing experiments at Portsmouth, and trying various coverings and amounts of covering, and various kinds of covering are being used as non-conductors of heat. As we try the auxiliary machinery of different ships we shall gradually accumulate some valuable information, which I shall have much pleasure in putting before the Institution, when we have had time to think it over. Then, as to distilling plant, Mr. Sawyer has rightly drawn attention to the fact that it is quite possible to get 35 tons of distilled water from a ton of coal. That confirms our previous experience of many years ago in the last Egyptian campaign, where you could put in distillers with triple or quadruple effect. We have had the same experience; but then again the question of space and weight comes in for use on board ship. Of course the point I have shown, and I expect it will be confirmed by further experiment, is that, with these engines that we do use of a simple type, it is more economical to use them just at that pressure which is sufficient to enable them to do their work. Mr. Yarrow has referred to the question of passing the exhaust into the low-pressure cylinders. The objection to doing that in warship machinery is the difficulty of manipulating the main engines. We do not make a voyage from one place to another for the sake only of making the voyage with the least consumption of coal, but the machinery must be entirely subordinate to the varying purposes of the ship. You may, at any moment, have to go to quarters, or to target practice, or to anything of that sort. The engines are slowed down from what they have been set at, and you would then add considerably to the number of things to be looked after, when the alteration of the speed of the engines takes place, otherwise we might be very glad to make use of the principle of using up the exhaust steam. We are thinking out the desirability of taking up some of the heat in the way of feed heaters and such like apparatus. We made a trial a little while ago illustrating the excessive expenditure in auxiliary machinery with a higher pressure of steam. In the *Arrogant* we made a 30 hours' trial at 1-5th the maximum horse-power. The result was 2·1 lbs. of coal consumed per indicated horse-power for the main engines, and ·8 lbs. for the auxiliary. That is the *Arrogant*, working at 300 lbs. of steam. In the *Venus*, working at 150 lbs. of steam, we had a 30 hours' trial at 1-5th maximum power. The consumption for the main engines was 2·1 lbs. per indicated horse-power, and the consumption for the auxiliary service came out at ·4 per indicated

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horse-power of the main engines. You see that, in the *Arrogant* with the higher pressure the consumption for the auxiliary purposes was just double what it was in the *Venus*.

Mr. SEATON: There would be no blowers in the *Venus*.

Sir JOHN DURSTON: No, there were no blowers in the *Venus*. This is only an isolated instance. I have not given one other piece of information, but I hope to do so later on, and that is the information with regard to the trials made at Paris on the boilers ashore, and also the trials made on the boilers ashore at our various contractors' works. That will come when we get more examples. Of course if we get a large number of examples the results are more trustworthy than with only a few. I beg to thank you, gentlemen, for listening to my paper.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): I feel certain, gentlemen, that you will desire to accord a hearty vote of thanks to Sir John Durston for the very interesting paper which he has read.

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RIVETING BY ELECTRICITY.

By Herr F. von Kodolitsch, Member.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 30, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

Most of the shipbuilding yards and bridge-building establishments are now seriously considering the question of introducing electric transmission of power into their works, for the sake of driving each tool by a separate motor. Some of the factories already possess a hydraulic installation for riveting purposes, which it would be impossible to convert to the new system. The only way of applying the new system to the existing plant would be to drive the compressor pumps by a separate electric motor. All the defects which belong to hydraulic installation in general would adhere to this, viz., a great outlay of capital, high working expenses, and an enormous cost in the up-keep.

For the last two years I have been experimenting on electric riveting machines, and have finally succeeded in bringing out a type of riveting machine quite capable of superseding the two systems already existing, viz., hydraulic and pneumatic riveting.

There are a good many firms in this country who have to decide which system of riveting they intend to adopt for the future, in order to keep pace with the rapidly increasing competition of other firms at home and abroad, and this is the reason that I propose to read a paper on this subject at the present meeting; especially as I have seen that some firms on the other side of the Atlantic are making great efforts to introduce the pneumatic system, and promise gigantic profits to those who decide to adopt it.

Before I proceed to describe the electric riveter in detail, I wish to point out, in a few remarks, why the electric system is, from the commercial and technical point of view, superior to all its rivals. I assume, of course, that the yard, adopting the new system, already possesses a central station and a system of wires for transmission of power, as is already the case in a good many establishments. If they are driving punching, shearing, or boring machines, rolls or mangles, &c., by the electric current, it is certainly logical to utilise this existing current also for riveting. Anyone deciding to rivet by electricity has only to order such a machine and place it where he wants to

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do his riveting, connect two wires from the main to the riveter, and he can begin the operation at once.

Now, let us suppose that hydraulic riveting has been decided upon. A pair of expensive compressor pumps have to be installed, a gigantic accumulator has to be put up, pipes must be laid. Pipe connections between the riveter and the accumulator have to be made, and a hydraulic riveting machine must be bought and erected. In case of pneumatic riveting, the same installations must be made, and almost the same outlay of capital is incurred.

What has been said above clearly demonstrates that the initial outlay is far less if the electric system be adopted. Everyone who works a hydraulic or pneumatic installation must know what a heavy item is the keep-up in the total working charges. In case of the electric system, this point only becomes a fraction of the expenditure.

As regards the quality of the work, there is not the slightest difference, but as regards the quantity of work done, the electric system is considerably superior. The machine I am describing to-day has closed, for weeks and weeks, 1,200 rivets in a day of ten hours' duration, requiring the attendance of only three men and a boy.

The electric riveting machines which have, up to the present, been built can be carried about easily to any place in the yard, but are not made for being suspended from a crane. To the large jaw are attached two platforms at right angles, so that the riveter may be used horizontally or vertically. The system is so very simple that I need not occupy much of your time in describing it. One heavy disc (Fig. 1, Plate VI.) is always rotating by electricity, whether the riveter is closing rivets or not. This disc can become, at the same time, an electro-magnetic coupling, so that, when the current is passing this coupling, a second disc, keyed on to a screw spindle, may be at once firmly attached to the revolving disc, thus the friction of the screw spindle can be regulated according to the operator's wish. The screw spindle moves a large nut at the end of a knuckle joint, which raises and lowers the die for making the rivet head. Between the two already mentioned discs a conical friction roller can be inserted. By pressing in this roller, the motion of the screw spindle can be reversed, and the nut of the knuckle joint returned to its original position in order to be ready for a new stroke.

The pressure on the die must be regulated in proportion to the diameter of the rivet, and this is done by producing more or less friction between the two discs, which difference in friction is obtained by more or less current being admitted to the electro-magnetic coupling.

The type of the riveting machine which we are building now, is made chiefly for shipbuilding purposes, and closes rivets up to 1⅛ in. in diameter; the output is, as already stated, 120 rivets per hour. When so many hot rivets are required in a short time the question of heating the rivets becomes very important.

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When we started to rivet by electricity, we could not produce the number of hot rivets required by using a reasonable number of portable forges. For this reason we have made a small fan, driven by an electric motor, to supply air to a number of small furnaces, which considerably reduces the number of boys required for heating rivets. The illustration (2, Plate VI.) shows this rivet-heating arrangement.

To illustrate the quality of riveting done by the new riveting machine I have brought with me the section through a riveted joint. You will see by this that the rivet holes are filled in completely, in the same manner as is done by a hydraulic riveting machine.

DISCUSSION.

Mr. JAMES HAMILTON (Member of Council): My Lord and Gentlemen, the writer of this paper says that the initial outlay is far less if the electric system be adopted; but, he seems to me, if I have gathered the sense of his paper properly, to have started on the assumption that one has all the plant for electricity for other purposes—for lighting, for instance; whereas, when he talks of the hydraulic system, or pneumatic system, he assumes that that has all got to be purchased. I think most of us have large hydraulic plant for cranes and derricks and other purposes which can be applied to riveting as well, and it might be interesting if the writer of this paper would make a comparison, and tell us what that comparison is, on the assumption that *all* the plant has to be purchased.

Mr. ARCHIBALD DENNY (Member of Council): My Lord and Gentlemen, I am not in the least surprised that Mr. Kodolitsch has invented this machine. I know that gentleman intimately, and he is a keen electrician; his works are quite extraordinary, and have been for some years, in the application of electrical power. It must not be forgotten that his country, Trieste, is one of those places where the heat in summer is fearful, but in winter the cold is equally severe, and a hydraulic system is thus a great trouble to him on account of the water freezing in the pipes; whereas, in our more temperate clime in Scotland we are not so much troubled with that. I do not know what the practice of the other yards is, but I made inquiries in our yard as to the number of rivets which could be closed by an ordinary hydraulic frame machine, riveting, and I found that 1,000 to 1,100 in an ordinary working day of 9¾ hours is quite usual, and one instance was given me where a squad of men had gone the length of 1,500 in one day. Of course it largely depends on whether the work is conveniently arranged, and if the men have to lose time in screwing up the frames, and so on, that is against them; but 1,000 to 1,200 is quite usual. This machine has a toggle joint, and toggle joint machines are proverbially difficult to handle, because a very small difference in the thickness of the plate or frame to be riveted makes an enormous difference in the pressure. Mr. Kodolitsch has an elastic break, and it may be that that gets over the difficulty; but I think, even with that, if you had varying thicknesses in the plates or frames you might get, as we got in the old power-driven riveting machines, a very different pressure on adjacent rivets. In the old days, I have been told, that sometimes the pressure varied so much that all the set was taken out of the frame, or beam, after it was riveted, and I think this machine may share that fault. I am sorry that Mr. Kodolitsch is not here to explain this point, because it is a little difficult to say off-hand whether this is so or not. In

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regard to the heating of the rivets, no doubt immediately you start riveting by machinery you are met with the difficulty of keeping the machine supplied with hot rivets. What we have found useful is a small furnace very much like a plate furnace. The fire is at one end, and the flame passes over a flat surface or shelf on which the rivets lie; these are put in and taken out of the furnace through small doors. With one of these furnaces, about 6 ft. by 3 ft. by 4 ft., you can keep one squad going putting in rivets at the rate of about 1,100 a day. It is a different system from that adopted by Mr. Kodolitsch, but the end attained is the same. This question of the development of electricity in yards is very interesting, and is becoming common in this country, and although, perhaps, I am out of order, I should like to say in reference to Sir John Durston's paper that I have not the slightest doubt that a large economy will result from driving auxiliary machinery by electricity on board ship.

Mr. W. T. Courtier-Dutton (Member): My Lord and Gentlemen, there are one or two short remarks that I should like to make, with your permission, on this paper. I am quite sure that shipbuilders and others connected with the construction of vessels will welcome anything in the way of mechanical riveting—any further development of mechanical riveting, and anything that will tend to minimise the human factor in riveting, which is, of course, a very uncertain element. In addition to other points which the author of this paper has brought forward, the question of the portability of this riveting machine is touched upon. He says it can be carried about easily to any place in the yard. Now, looking at the illustration (Plate VI.), it strikes me this is hardly the sort of machine a man can put on his shoulder and run about with, and that it is, in fact, a very much heavier and more massive article than the usual hydraulic riveter in use in the yards. I think it would, perhaps, be well if the author were to furnish us with some idea of the weight of this machine, as bearing upon the question of its portability compared with the ordinary hydraulic riveter. Then there is one other point. It seems to me rather a waste of power to have a machine which is capable of closing rivets up to 1¼ in. in diameter, constantly running. No doubt less powerful machines can be made, but the one illustrated here is evidently intended for use in the shipyard, as it is shown to be closing rivets in a floor-plate with frame and reverse bar. The ordinary parts of a vessel's structure which are riveted together before being worked into the hull of the vessel do not usually require rivets up to 1⅛ in. diameter. I think, for all practical purposes, riveting up to ⅞ in. is all that is wanted, so that it appears to me that a machine of a much lighter character than the one dealt with here would fulfil all necessary purposes. I think, my Lord, that is all I have to say.

Mr. Henry M. Napier (Member): My Lord and Gentlemen, no subject is more important to the shipbuilder or manufacturer than that of machine tools, and it is becoming more and more so as the demand for economy in production increases. I have had some experience in riveting by pneumatic machines, the design of which is very similar to that of Mr. Kodolitsch, the chief difference being in the mechanism for giving the thrust. In both cases the requisite pressure on the rivet head is obtained by an elbow-joint motion. No doubt the electric machine can do work quickly, as any riveter ought to, if hot rivets are supplied in sufficient quantity. As to the design, the motor running continuously does not appear very economical, and the reversing gear for the up stroke is simple, but it looks as if the wear and tear would be great. Mr. Kodolitsch has produced a very ingenious riveter; but anyone proposing to adopt it should consider the whole system, so as not to have an unnecessary multiplication of pipes and wires. As to pneumatic power, with a pressure of only 70 lbs. per square inch there is but little trouble from leakage, and the same pipes supply riveters, blow rivet fires, and blast lamps, while drilling machines and caulking tools can also be worked. Neither hydraulic nor electric power has as yet been brought to do such a variety of work. Far be it from

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me to say anything against electric motors, or this riveter in particular. If electricity could do everything wanted in a workship, nothing would be better, but that day is still in the future.

Mr. J. Macfarlane Gray (Member of Council): My Lord, may I make the remark that, thirty-four years ago, I put down inch rivets at the rate of three in a minute with a portable riveter weighing 21 lbs., working sometimes with steam and sometimes with compressed air. It pleased everybody who saw it, but the tools would not stand the fatigue and the manufacture was abandoned.

The President (the Right. Hon. the Earl of Hopetoun, G.C.M.G.): As no other gentleman desires to speak on this paper I think we may take it upon ourselves to request the Secretary to convey our best thanks to this gentleman for the very interesting paper he has sent us, and I may also remind you that Mr. Dudgeon will be very happy to show you the different things referred to and the model, and also to give you an exhibition of riveting.

The following letter, in reply to the discussion on his paper, has been received from Herr von Kodolitsch:—

Dear Sir, *June* 11, 1898.

In reply to your letter of June 1, I should like to add to the discussion of my paper on riveting by electricity, that some of the remarks made cannot be applied to my riveting machine.

There is, first, Mr. James Hamilton considering total cost of introducing such a machine into a shipyard. Certainly, if the cost of placing an electric central station is added to the cost of an electric riveting machine, the total cost will become very large. But as, to-day, modern shipyards possess already electric transmission of power, riveting by electricity can be done by only buying such a machine.

Mr. Courtier-Dutton: the weight of this machine is about $1\frac{1}{4}$ tons, and it rests on no solid foundation, but merely on two pieces of timber, which form a sledge on which the machine can be carried about the yard. In case only rivets of $\frac{7}{8}$ in. diameter are to be closed, the weight of this machine could be considerably reduced, to, say, about three-quarters of a ton.

Mr. Henry M. Napier: in riveting with this machine it makes no difference if 1, 2, 3, or 4 thicknesses of plate are to be riveted together. There is always the same amount of pressure put upon the rivet head.

If you will kindly add these remarks to the discussion, you will greatly oblige,

Yours very truly,

F. KODOLITSCH.

George Holmes, Esq.,

Secretary Institution of Naval Architects,

5, Adelphi-terrace, London, W.C.

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INVESTIGATION OF THE NATURE OF SURFACE RESISTANCE OF WATER AND OF STREAM-LINE MOTION UNDER CERTAIN EXPERIMENTAL CONDITIONS.

Second Paper.

By Professor H. S. Hele-Shaw, LL.D.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 30, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

Introduction.

When the author was honoured by the Council with an invitation to read at the present meeting a second paper pursuing still further the subject treated by him in a contribution before the International Congress of Naval Architects in July of last year (Proceedings of I.N.A., Vol. XXXIX.), he felt that, in order to prepare his further work for publication in time, it was necessary to have some assistance, as the experiments and details would involve continuous attention and application, and this his own duties prevented him from giving. Accordingly, Dr. Elgar, F.R.S., with great kindness placed at his disposal, during the last few weeks, the services of Mr. W. H. Riddlesworth, B.Sc., a former student of the author, at present holding the Engineering Scholarship of the Victoria University, and acting as private assistant to Dr. Elgar, and it is due to Mr. Riddlesworth to say that, without his invaluable assistance, the author could not have complied with the request of the Council. Mr. Okill, his workshop assistant, has also rendered great service in constructing apparatus and carrying out the experiments.

But, beyond this, he has to thank Mr. A. L. Jones, of Messrs. Elder, Dempster & Co., of Liverpool, for most kindly defraying the cost involved in the construction of several pieces of apparatus, and various incidental expenses.

Scope of Paper.

The paper is divided into two sections, the first of which is a further investigation of flowing water under the conditions described and exhibited on the occasion

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above referred to. The object of this investigation was to further examine the theory set forth in the author's paper that the clear film or border line was a zone of parallel flow or stream-line motion.

The second introduces entirely new experiments by means of specially designed apparatus, which, though having an important bearing on the question discussed in the previous section, enables true stream-line motion to be continuously secured. It is shown by a comparison of the figures thus obtained and those calculated and plotted in cases where it is possible to arrive at results mathematically, that they are practically identical. Hence, the forms of stream lines for any given figure which may not adapt itself to mathematical treatment, can directly be obtained experimentally.

Section I.—Further Observations on the Sinuous Motion of Water, as Made Visible by Means of Air.

It will be remembered that the effect of admitting or forcing air into the water in a state of sinuous flow was to darken the main body of the flowing stream or jet, and that, apart from the lines of flow which were thus made visible, and the eddying effect which was capable of direct observation, there was also visible in every experiment, as projected on the screen by means of the lantern, or in photographs taken directly from the lantern, a clear border line.

The theory advanced was that this clear border line represented a condition of irrotational flow as distinguished from the state of sinuous or rotational flow in the main body of the water.

Since the reading of the previous paper, no criticism or comment has been offered upon the foregoing hypothesis, which, apart from its scientific bearing, must, from the remarks on that occasion of many of our distinguished members, evidently be regarded as involving practical questions of great importance.

There are, no doubt, *à priori* reasons for thinking it possible that the film of water which exists on the solid boundary of the liquid, when the general body of it is broken up into sinuous motion, is only of molecular thickness. On the other hand, the clear border on the boundary of the stream in the author's experiments would be at least many thousands of molecules in thickness. Seeing what an important part of the whole resistance of a ship is due to skin friction, to say nothing of the even greater portion of resistance occurring in pipes, which is directly concerned with the action of the boundary in question, a further examination of this matter with the view of either confirming the above theory or finding out some other explanation of the clear border-line seemed highly desirable.

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(1) In the first place, the author made a number of comparative experiments on bodies with ordinary water in which air existed, and also with water mixed with various substances, of which latter photographic reproductions are given for the cases in which soapy water was employed as giving much finer bubbles than with pure water. It should be remarked that the exposure was much more rapid than with the figures in the author's previous paper, being only $\frac{1}{100}$th of a second. The figures are arranged in pairs, those on the right hand being the result of using soapy water, and on the left, water only. Figs. 1 and 2, Plate VII., are circular cross-sections with a smooth surface, Figs. 3 and 4 with a rough surface. Figs. 5, 6, and 7 are cases of rectangular bodies broadside on to the stream, whilst in Figs. 8 and 9, Plate VIII., the same body is placed edgeways. Fig. 7 is a remarkable case in which an oscillation in the flow has been taken, and the whirls behind the body are visible. It should be particularly noted that in Figs. 5, 6, 8, and 9 the clear space behind the body is filled with water at rest. The large bubbles in all cases behind the body slowly circulate in the rear part of this clear quiescent water. When colouring matter is suddenly injected into the inflowing water it takes some appreciable time to find its way into this clear body of water. When the inflow of coloured water ceases this quiescent water remains coloured for some time after the main body of the water has become colourless. These facts have an important bearing in connection with subsequent remarks.

The difference between effects with pure and with soapy water, in both of which air was mixed, will be easily recognised from the more finely divided state of the bubbles in the soapy water.

In all these experiments, the clear border line is always quite visible, but it is smaller with the soap solution than with water alone.

The influence of air in the lines of flow is also quite obvious, and is shown by the difference in the case of the soap solution, where the bubbles are very much smaller and therefore have less effect than in the ordinary case. This fact, apparently, accounts for the different nature in the film in the two cases. The general character of the difference in the two kinds of experiments, for the flow round both rectangular and circular bodies may be briefly described by saying the lines with soapy water approach more directly to the obstacle, and do not so readily close in behind, continuing to move parallel for some distance behind it. In the case of the larger bubbles on the figures in the left hand, the curve of approach is more gradual, and the closing in behind more direct when the obstacle is passed.

(2) The effect of varying the nature of the surface was investigated in two ways:— (1) A series of rings, coated with different materials, which could be slipped on over a cylindrical body in the slide was used, with results which are shown in Figs. 1 to 4. Figs. 1 and 2 are examples of smooth brass surfaces, Figs. 3 and 4 are examples of

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rough sand surfaces. (2) A trumpet-shaped form was used, one side of which was smooth polished lead, and always the same, while the other was coated with various materials, so that a direct comparison could be instituted. Figs. 10 and 11, Plate VIII., give illustrations of these effects, Fig. 10 of paraffin, Fig. 11 of sand; and, contrary to what the author previously thought, the rougher the surface the narrower was the clear border upon it, while on the smooth surface, in all cases, the widest film existed. On some of the rougher surfaces the film was scarcely visible at all. Hot water, with a viscosity about half that of the cold water was tried, but with no appreciably different results; at any rate, there appeared to be no differences which were capable of measurement. Oxygen and carbon dioxide were also tried in place of air, and gave practically the same results as air. The latter was used under the hope that, at places of less pressure, the gas would be liberated from the solution in water; but it was found that the flow occurred in a very spasmodic and jerky manner, though, on some occasions, the clear film was even more marked with this gas than with air.

Whatever might be the ultimate explanation of the clear film, it is not very easy to see why the air should refuse to go into it, unless on the assumption that the slower velocity of the moving particles at that portion resulted in a greater pressure, and therefore the water itself, having a greater inertia, was naturally able to find its way there to the exclusion of the air. Now, in the illustrations in the last paper, it was clear that both convex and concave surfaces showed a clear film; but it seemed desirable to make an experiment so that the convex and concave side could be compared under exactly similar circumstances of velocity and flow. For this purpose an S-shaped section of a pipe having two complete bends was designed, in order to ascertain what difference of effect was to be seen on the inner and outer sides. The result is shown in Figs. 12 and 13, Plate VIII. It will be noticed in Fig. 12 that there is a comparatively wide, clear film on the outer sides of the bends; at the same time, this is not very sharply defined or abruptly divided from the darker portion containing the air. Round the inner side of the bend, the bulk of the air would naturally be forced, and here it might reasonably be expected, unless the author's hypothesis is correct, there would be no film at all. There *is*, however, a clear border on the *inner* as well as on the outer side; this, moreover, is much more clearly defined, and has a darker line of demarcation, and is much narrower in width, thus clearly showing the natural tendency of the air to force itself against the skin which it is obviously not able to reach, presumably because of a layer of more slowly moving water. Fig. 13 shows the case with very little air, which, however, finds its way to the inner side of the bend, and makes the film quite visible.

(4) But there is one test which appears to be more important than all the rest, viz., the actual behaviour of a very thin sheet of flowing water. A trumpet-shaped

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mouthpiece has already been used. Fig. 14, Plate IX., shows a carefully photographed example of this in which the clear film is visible throughout. Fig. 15 shows the effect of contracting the narrow portion of such a mouthpiece to a very narrow space, viz., ·025 of an inch. In this case the air is no longer visible, and appears to pass through in a very different state to that in which it passes through the wider portion, and the use of air for purposes of examination quite fails. Now, it will be remembered that, in the previous paper, attention was called to the fact that, where the velocity was greatest, the film was thinnest. If, now, the thickness of a sheet of water is about equal to that of the film at a corresponding velocity, stream-line motion in the sheet should, if the thin film theory is correct, be obtained. This, as will be afterwards seen, has been proved to be, beyond all doubt, the case. By a special contrivance, sheets of water in which the phenomena of stream-line motion can be exactly produced were constructed, and the results, so obtained, have enabled this apparatus to be used for specially obtaining stream-line forms which can be compared with those arrived at by means of mathematical investigation. The subject has developed in such a way as to necessitate its treatment at length in a separate section. It is not hard to understand, in view of what has already been said, why the use of air failed to produce a film or border line with thin sheets, whereas such a film occurred with the use of comparatively thick sheets of water. The bubbles of gas or air appeared to collect into one large body and go though at intervals, sweeping out the water so that alternate bodies of gas and water passed through in succession. The only exception to this was with a particular state of regulation very difficult to hit upon, and more difficult to maintain, when very minute bubbles of gas issuing from small holes in a separate cross supply pipe took the form of stream lines themselves.

Section II.—The Production and Experimental Investigation of Stream-Line Motion.

In order to obtain a thin sheet of water, the new piece of apparatus shown in Fig. 16, Plate IX., was designed. The sectional view shows that a piece of plate glass with rounded ends (such as A) is inserted in the ordinary slide, thus forming a small reservoir at the ends into which the water first flows, thence passing as a thin sheet through the main portion of the slide. At first colour was admitted by means of a cross tube B, with very small holes at regular distances apart, and certain colour-band effects of a more or less blurred character were obtained. It was seen that the blurring effect resulted from the admission of the colour into the small reservoir where sinuous or rotational motion of the water existed. It became evident that the colour bands must be introduced into the thin sheet of water itself, and Fig. 17 shows in section how this was done. The brass block C was fitted at the entrance to the thin

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sheet, and had a row of very fine holes leading to a hollow centre through which the colour was introduced from the outside.* This acted admirably, and the apparatus in this form gave permanent and perfectly steady colour bands showing stream lines to exist up to very high velocities; in fact, never breaking up at all at the highest speeds due to the available pressure head.

For examining and photographing the effects, the arrangements shown in Figs. 18 and 19, Plate X., were respectively employed. The supply and waste pipes for the main body of water are shown, the latter above, the former below, the electric lantern. The pump for supplying colour for the colour bands is also shown. In Fig. 18 is the small water slide in which most of the work for the present paper was done, the screen used for observing and plotting results being also shown. In Fig. 19 is a large water-slide which is fixed to a separate frame, which requires, however, such careful adjustment for steady colour band effects that it has not been used for any of the results published in the present paper.

When an obstacle of unfair form, such as a plate or the cross-section of a circular cylinder, was introduced, steady flow of the water round it was maintained up to a certain point. Beyond this point those colour bands, in the path of which the obstacle was placed, although passing round it as before, did not remain perfectly steady after doing so, so as to regain their original form, but became more or less blurred; the alteration of the inflowing water supply in the slightest degree could intensify or diminish this blurring effect. There was, however, always a velocity for which apparently perfect stream-line motion round an obstacle, whatever its shape, could be produced and maintained.

The above results seem to prove definitely the existence of a zone of parallel or irrotational flow corresponding to the thin film which has been so fully discussed. It will be remembered that, in the author's previous paper, special experiments were illustrated showing the thickness of the film to be diminished as the velocity was increased, and, in describing them, it had been said that the experiments "bear out the view that the width of the film decreases with increase of surface velocity."

Now, in one case, careful measurements, by means of distance pieces, of the thin sheet in the new apparatus, proved that it was ·025 ($\frac{1}{40}$) in. thick. For this thickness

* NOTE.—The greatest difficulty was experienced in finding suitable colouring material for photographing the stream lines. When aniline dye was used in sufficient density to give a clear line in the photograph, the fine holes soon became choked. Permanganate of potash gives beautiful results from an optical point of view on the screen, but were of little use for photographing direct. At last, after many trials, a mixture of pyrogallic acid and iron sulphate, neutralised with ammonia, was used, the non-actinic properties of which are excellent. The stream lines are so steady that they can be photographed from the projected image on the screen.

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of sheet, the stream lines, although, while straight, perfectly stable up to any velocity, were not, beyond a certain velocity, stable after passing round a plate broadside to the stream. The frame was then carefully worked down to make the thickness ·02 ($\frac{1}{50}$) in.; it was then found that stability could be secured after passing the obstacle at a velocity much beyond the limit in the previous case.

The relation between the velocity and thickness of the film might thus have been investigated, or, in other words, the critical velocity for thin sheets of water under different circumstances; but, inasmuch as the forms of the stream lines themselves were slightly different at different velocities, when what appeared to be a critical velocity was exceeded, and probably the question of viscosity was involved, it was evident that the whole subject would require a considerable amount of time to properly investigate it. On the other hand there appeared such a new and important field opened up for investigation of the shape of stream lines themselves under various conditions, and, in particular, the comparison, by means of experimental results, when true stream-line motion was ensured by a limited velocity, with those of mathematical investigation on the subject, that it was thought better for the present to proceed with the latter research.

Investigation of the Case of Plane Motion past a Circular Cylinder.

In order to arrive at some definite results, it was felt that the best thing to do was to take a case for which the stream function was known, and for which plotted stream lines could be obtained without inordinate numerical labour.

Such a case, in two dimensions of space, is that of a circular cylinder moving through a fluid of infinite extent with its axis perpendicular to its plane of motion, the stream function for which is—

$$\psi = -\frac{u a^2}{r} \sin \theta.$$

By impressing a velocity equal and opposite to that of the cylinder upon the whole system, the case of an infinitely wide stream flowing past a stationary cylinder, and perpendicular to its axis, is obtained, the value of the stream function being then—

$$\psi = u \left(r - \frac{a^2}{r}\right) \sin \theta.$$

This is a somewhat similar case to that which is obtained with a section of cylindrical form in the slide of the lantern. The difference between the two is, however, to be found in the fact that the lantern slides used were necessarily limited in dimensions, and, therefore, although it might be interesting to compare the two cases, a more correct value of the stream function suited to the altered conditions was necessary. It was clear that there was a possible solution for a channel with a cylinder in it by investigating the effect of a stream flowing past an indefinite number of equidistant cylinders placed in a row, the distance apart being the width of the channel. The

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result would then give, midway between each, a stream line parallel to the original stream, across which, of course, no flow would take place, and which, therefore, could be considered a fixed straight boundary, and hence the actual condition of the channel in the lantern slide, or, on a larger scale, of the effect in a canal or river would be obtained.

The author is indebted to Professor Lamb, F.R.S., for kindly responding to his request and working out this problem.

The following gives the approximate value of the stream function for this case—

$$\frac{\psi}{u} = x - \frac{\pi c^2}{a} \frac{\sin \frac{2\pi x}{a}}{\cosh \frac{2\pi y}{a} - \cos \frac{2\pi x}{a}},$$

where—

a = width of canal.
c = radius of cylinder.
u = initial velocity of stream.

The solution of this equation, in order to obtain points on the stream lines for comparison with the experimental results, was by no means an easy matter, and, instead of the ordinary method of finding a number of points directly, the special method devised will be found explained and worked out in the Appendix.

The table below has been prepared to suit the dimensions of the cylinder actually used and the distance apart of the initial stream lines employed in the lantern slide. The curves, although photographed and reproduced, were really plotted on a large scale on the screen; the stream being perfectly steady, could be marked down with fair accuracy scarcely possible on a smaller scale in a photograph, and the comparative results are set forth in the table, while a segment of the figure is given for comparison on a larger scale.

1. On projecting the figure on a screen on which had been drawn the stream lines given by the equation (plotted in Fig. 20, Plate XI.), so that the two could be easily and directly compared, several important discrepancies were at first evident; but these, on more careful examination, were found to be due to defects in the apparatus, a very small inequality in the thickness of the sheet, or a want of perfect jointing at the edges on the inside glass plate, producing marked effects. As improvements were made, the projected figure came closer and closer into agreement with the theoretical one, and it was quite obvious that, for all practical purposes, the two really agreed when the velocities of the flow were kept down below a certain limit.

The annexed table is the result of plotting the curves, so obtained, from the equation of the approximate value of the stream function and the actual results of experiments.

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COMPARISON OF STREAM-LINE CURVES FOR THE CASE OF FLOW PAST A CIRCULAR CYLINDER IN A NARROW CANAL.

Measurements in Number of Thousandths of the Semi-width of Canal, from Axis of Symmetry through Centre of Cylinder.

Values of Station Ordinates (y_1).		Stream Lines in Roman Numerals.								
		I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
0	Theoretical	389	435	494	560	630	704	777	852	925
	Actual ..	392	455	505	565	630	704	772	850	930
	Error ..	+ 3	+ 20	+ 11	+ 5	0	0	− 5	− 2	+ 5
1	Theoretical	350	407	472	545	620	693	770	848	925
	Actual ..	350 354	410 413	482 480	550 550	620 621	694 692	765 768	844 850	927 930
	Error ..	0 + 4	+ 3 + 5	+ 10 + 8	+ 5 + 5	0 + 1	+ 1 − 1	− 5 − 2	− 4 + 2	+ 2 + 5
2	Theoretical	216	323	421	508	592	674	756	839	923
	Actual ..	210 200	315 315	415 415	500 500	583 580	670 668	750 752	840 842	924 920
	Error ..	− 6 − 16	− 8 − 8	− 6 − 6	− 8 − 8	− 9 − 12	− 4 − 6	− 6 − 4	+ 1 + 3	+ 1 − 3
3	Theoretical	140	257	364	465	557	652	738	825	915
	Actual ..	130 143	247 262	360 370	455 460	553 555	642 650	735 738	822 834	920 925
	Error ..	− 10 + 3	− 10 + 5	− 4 − 6	− 10 − 5	− 4 − 2	− 10 − 2	+ 5 0	− 3 + 9	+ 5 + 10
4	Theoretical	119	228	332	436	534	632	724	815	909
	Actual ..	112 115	215 230	322 338	421 435	520 540	620 638	717 732	815 824	912 920
	Error ..	− 7 − 4	− 13 + 2	− 10 + 6	− 15 − 1	− 14 + 6	− 12 + 6	− 7 + 8	0 + 9	+ 3 + 11
5	Theoretical	108	213	317	420	520	619	712	807	905
	Actual ..	100 100	206 212	310 318	408 420	512 523	610 624	710 725	811 818	912 910
	Error ..	− 8 − 8	− 7 − 1	− 7 + 1	− 12 0	− 8 + 3	− 9 + 5	− 2 + 13	+ 4 + 11	− 3 + 5

The figures in the table represent the position of a number of points on each stream line in terms of a unit which is $\frac{1}{1000}$ part of the width of the semi-canal used in the experiments, which is itself only $1\frac{7}{8}$ in. in width. It will be seen that the maximum errors are + 20, and − 16, representing an actual displacement of the stream lines of ·038 in. and ·029 in. respectively.

Although the differences are appreciable, they are to some extent of a nature which must be attributed to the great difficulty, in the first case, of making sufficiently accurate mechanical arrangements, and also from the fact that it takes some little time to plot down the results, and that, during this time, it is extremely difficult with the present appliances to keep a *perfectly* steady and uniform pressure both of the colouring bands, and the main body of water, when each comes from a separate source. Beyond this, however, there is no doubt that the stream lines are slightly pushed away from the

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obstacle at the point of greatest velocity, *i.e.*, abreast the mid-section; this may be due to the slight effect of viscuous resistance parallel to two containing glass boundaries. This would mean that the distribution of velocity in this region was more uniform than would be the case for a perfect fluid. At the same time, the formula used is only an approximation, though used within limits that should give a very fair accuracy.

From a practical point of view, it may, therefore, be fairly claimed that the results justify the application of this experimental method to other cases. The actual photograph of the stream lines round the semi-cylinder is shown in Fig. 21, Plate XI. In Figs. 22 and 23 are given the stream lines showing the flow round a complete cylinder, the former being the result of experiment made with narrow colour bands and the latter being taken from Lamb's Hydrodynamics. The two figures do not exactly correspond in either the pitch of the stream lines, or their relative position. The latter has a central stream line, while the former has not, and the curves of the two adjacent stream lines are therefore not the same in both cases. Moreover, the latter is for the case of an infinite fluid, and the former for a channel with straight sides. The comparison of the two is all the more interesting for these reasons.

2. The problem of obtaining stream lines in the restricted dimensions of a channel with parallel sides, such as with the appliances which have been described, is by no means an easy one, and the only other mathematical case which the author is aware of is that which may be derived from the analogous case worked out for the theory of a grating of parallel wires in Clerk Maxwell's " Electricity and Magnetism," third edition, vol. i., page 310. The value of the potential is here investigated for the case of an infinite series of fine wires, which act as a grating in the side of a metallic vessel surrounding a conductor, to prevent the body outside from being electrified by induction. The lines of force thus obtained correspond exactly with the stream lines of flow in a parallel channel of width equal to the distance apart between the wires, the water in the channel escaping through a small hole (constituting a " sink " in hydrodynamics) in the middle. Fig. 24, Plate XI., gives the stream bands corresponding to this case, which can be compared with the theoretical figure in the above work.

3. Another mode of verification might be afforded by the direct measurement of the position of the point where the central stream line strikes an inclined plate placed in a stream. Professor Lamb has shown mathematically that, when the plate is inclined at 45°, the shape of the central stream line is a hyperbola, meeting the plate at right angles, and separating in both directions; the exact distance and position of the point at which the central line strikes the plate having been worked out by him, and plotted for this case, as well as the other stream lines. The case is, of course, for an infinite width of stream, and it does not seem easy to find any approximation for the flow in a channel. Since, however, across stream lines no flow takes place, any

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convenient one of these lines from the above case may be taken as the border line of a curved channel. Hence this and other figures which can be worked out for an obstacle in an infinite fluid can be compared directly with those obtained experimentally. Of course the assumption made by doing this is that the lines are already correct, but after all, if the two methods are in agreement, there are a sufficient number of lines remaining inside the assumed boundaries to afford a very fair check on the result.

In response to an inquiry from the author as to the exact numerical value of the distance in question, Professor Lamb kindly looked into the matter, and obtained the following value of the distance of a point of section from the centre of the plate :—

$$d = a \cos \theta$$

where—

$2a$ = width of plate

and

θ = angle of inclination of axis to the stream.

By means of this very elegant result the author arranged a simple graphical method of checking the experimental observations, viz., two circles separated by a thickness equal to the thickness of the plate, each of a diameter equal to half the width of the plate, the centres of both being in the line of undisturbed flow through the centre of the plate. The intersection of these circles with the edge of the plate should be at a point where the central stream line meets it.

Fig. 25, Plate XII., shows this construction applied to the figure given in Professor Lamb's treatise and the general appearance of the stream lines in that case. Fig. 26 shows the result of the actual experiment, the colour bands being only tolerably narrow. When, however, sufficiently narrow, the point of intersection of the central line not only absolutely coincided with the point theoretically obtained, but the curve itself seemed to be of the same form. In this case, however, the lines are too fine for photographic reproduction.

Fig. 27, Plate XII., shows the effects of using wider colour bands; the central one, being very much reduced in velocity as it approaches the plate, widens out proportionally, and then flows in either direction. It will be noticed that only a portion flows actually along the back of the plate, the other two portions taking more direct routes to join the central band in the rear of the plate. The general confirmation of theoretical conclusions by practical experiment is thus complete.

Fig. 28, Plate XII., is inserted as being an interesting case of the effect of vibration. The author's experimental laboratory is subject to vibration due to the engines in the main laboratories below, and in several cases photographs had to be taken at night or the engines had to be stopped, because of the evident instability of the stream lines

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after passing round the sharp edges of an obstacle, when subjected to this amount of vibration.

In connection with this, there is a matter which should be mentioned. Lord Rayleigh gave (*Phil. Magazine*, December, 1876) an expression for the distance (d) of the point in question from the leading edge of the plate (the width of the plate being unity) as

$$d = \frac{2 - 4\cos\alpha + 2\cos^3\alpha + \alpha\sin\alpha}{4 + \pi\sin\alpha}$$

where α = the angle made by the plate with the direction of undisturbed flow. This curve will be found plotted on page 16 in the work on "Resistance of Ships," by Mr. W. D. Taylor, and it is quite clear that the values given for this formula differ from that given by Professor Lamb (see Appendix No. 2). On looking more closely at Lord Rayleigh's paper, it is evident the conditions of flow, which he deals with, correspond rather to the cases which were represented by the author's experiments with thicker sheets of water when the motion was sinuous, and where it is quite possible to have a body of quiescent or nearly quiescent water behind the plate, as shown in the diagrams in the early part of the present paper, and also in the previous paper of the author, and it would be extremely interesting to investigate the exact position at which the stream divides on meeting the plate at different angles for conditions in which, although stream-line motion may hold in front of the plate, yet in the rear of it, at any rate, inside a certain boundary sinuous motion takes place. It may be pointed out that in the Figs. 5 to 9, showing flow past a rectangular solid, the dense black curves springing tangentially from the front face of the obstacle bear a remarkable resemblance to the curves of the surface of discontinuity, which is dealt with by Lord Rayleigh and assumed to exist in his calculations. The existence of this surface has formed the subject of critical discussion in a series of articles in *Nature* (Vol. 50) by Lord Kelvin. In the third of these articles, Lord Kelvin says: "The assumption to which I object as being inconsistent with hydrodynamics, and very far from any approximation to the truth for an inviscid, incompressible fluid in any circumstances, and utterly at variance with observation of discs or blades (as oar blades) caused to move through water, is that, starting from the edge, as represented by the two continuous curves in the diagram, and extending indefinitely rearwards, there is a 'surface of discontinuity' on the outside of which the water flows, relatively to the disc, with velocity V, and on the inside there is a rear-less mass of 'dead water' following close after the disc." In the author's experiments this effect in the rear of the plate certainly extends only to a finite distance; but, as the velocity is increased, it is drawn out to an ever-increasing distance, and in some of the experiments extended as far as the limit of the frame would permit.

The visibility of the lines in the author's experiments is accounted for by the fact

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that a mass of fine bubbles of air in rotation exists at each edge which is kept circulating round, the appearance to the eye being that of a bright crystalline mass. This leaves a thin clear film in the opposite direction to the general flow, quite close to the obstacle, being kept circulating by its contact with a surface outside, which, though not strictly a surface of "discontinuity," has to a certain extent this property, inasmuch as there is practically dead water on one side, and water at a high velocity on the other. Further experiments on this point seem desirable, as tending to throw some light on this intricate point, particularly as there is such a marked difference in the behaviour of the thick and thin sheets of water. Further, it is always assumed in theory that the stream lines are the same for a body moving through a mass of perfect fluid as for a mass of fluid moving past a stationary body. It is quite a different matter, however, in practical cases of relative motion where disturbing causes may be at work, to make the above assumption, and more experimental knowledge on the subject is also required.

A stream line taken from the case of an infinite fluid may be used as an artificial boundary for certain other cases of stream-line flow, one being that of a parallel stream flowing into a sink, which should form a similar figure to that of a source combined with an infinite stream given in Professor Rankine's paper on "Plane Water Lines" (Phil. Trans., 1864); the stream lines thus obtained are shown in Fig. 29, Plate XII., and may be compared with the diagrams cited, and with those in Mr. D. W. Taylor's paper ("Ship-shaped Stream Forms," Trans. I.N.A., Vol. XXXVI.). The distribution of the stream lines in the experimental case is rather different to that of the other cases, owing to the experimental colour bands being injected at equal distances near the sink; whereas, in the other cases, the stream lines are equidistant at an infinitely great distance from the sink. The general similarity is, however, very marked, and particularly the form of the dividing line (A A) (called by Mr. Taylor "stream form") between the fluid which flows past the sink and that which passes out through the sink. Fig. 30 shows a rather different distribution of stream lines for this case.

An artificial "source" can be made to supply a radiating stream in the following way. The simple pipe shown in Fig. 31, Plate XIII., is surrounded by an annulus into which passes colouring matter. This colouring matter flows into the thin sheet of water in the experimental apparatus, through a series of fine holes carefully spaced and drilled so as to direct the jet of colour as nearly in the plane of the sheet as possible. Through the centre a stream of uncoloured water, constituting a source, passes. Using this arrangement, one other case is given. This is the stream lines for a combination of a sink and source. The stream lines for this case are circles passing through both source and sink, and hence the artificial boundary is easily made, and all the stream lines within are readily checked. It will be seen from the photographs

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(Fig. 32, Plate XIII.) that the stream lines thus experimentally produced fulfil the theoretical conditions.

Stream Lines of Interest Occurring in Practice.

Having thus shown the agreement between stream lines experimentally produced and those obtained on theoretical principles, a certain number of examples may be given of cases of interest.

In the first place, the stream lines for a rectangular body placed broadside and endways to the stream are given (Figs. 33 and 34, Plate XIII.), and may be compared with those obtained under different conditions of flow (Figs. 5 to 9), in which there is a boundary between the flowing and the quiescent body of water, and also with the corresponding figures given in the author's previous paper.

The next case taken is that of the propeller shaft struts of a twin-screw steamer, particulars of which were kindly furnished by Dr. Elgar. In this case the stream lines are shown, not only with broad and narrow colour bands (Figs. 35 to 38, Plates XIII. and XIV.), but the effect is also given in Figs. 39 and 40, Plate XIV., of employing a thicker stream of water as in the original experiments, where air is used to make the effects visible. It will be noticed that, for simple stream-line motion, there is no practical difference whichever way the body is turned, whereas, in the other case, a very marked difference results, and bears out the dictum of Froude, "It is blunt tails rather than blunt noses that cause eddies."

Figs. 41 and 42, Plate XIV., show the mid-section of a dolphin, the lines of which were taken from a stranded fish by Mr. Sydney Barnaby, of Messrs. Thornycroft & Co., and kindly given to the author. The stream lines are shown for both vertical and horizontal sections, and, though not corresponding with those of the actual body in three dimensions, may be of interest.

Figs. 43 and 44, Plate XV., give the case of a ship-shape form obtained by Mr. Taylor, in his paper, for the two cases of narrow and wide colour bands in a thin sheet of water, and may be compared with the stream lines given by him.

Another case (Figs. 45, 46, 47, and 48, Plate XV.) which is given, is a section suggested to the author by his friend Mr. Henry H. West, in which, again, for stream-line motion there is no apparent difference whichever way the stream flows. When the same body is immersed in a thicker stream and the stream lines are broken up, the effect of pointing the arrow head against the direction of flow is seen to produce a far greater eddying motion than in the reversed position, which is quite contrary to what would naturally be supposed.

The remaining examples are cases of flow through channels. The trumpet-shaped passage in Fig. 49, Plate XVI., shows the perfect nature of the stream-line action.

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In this figure the narrow portion of the trumpet is so reduced as to make the stream lines almost invisible to the eye, and yet they do not in any way mix with each other or with the surrounding water, but emerge again perfectly distinct, and there is no tendency to break up in the narrow portion of the channel.

Figs. 50, 51, and 52, Plate XVI., show three cases of the flow through a gradually enlarged and then contracted section. The two former are cases of irrotational motion, whilst the latter is a case of sinuous motion in the thicker sheets used in the earlier experiments.

The last cases, which are given in Figs. 53 to 56, Plate XVII., are examples of sudden contraction and expansion in pipes. Figs. 53 and 54 show the effect of sudden contraction and expansion, respectively, with stream-line motion, made clear by colour bands, while for the sake of comparison, Figs. 55 and 56 are cases in which a thick sheet of water is employed when simple stream-line motion no longer takes place, air being used for making the behaviour of the water visible.

It is remarkable that, as long as stream-line motion takes place, there is nothing between the cases of expansion and contraction to indicate any differences of resistance to the flow, if indeed there is any resistance at all beyond that due to the parallel containing glass plates. In the case of sudden expansion for sinuous or rotational motion, the eddying motion, or disturbance, produced in the water is very much the greater, and points to what has been arrived at both on practical and experimental grounds, that the resistance in a sudden enlargement of a pipe is many times greater than a corresponding contraction, and in fact obeys a definite law.

Figs. 57 and 58, Plate XVII., contrast the case of stream-line motion through a pipe in which an obstruction occurs, in the shape of a pierced diaphragm, with that in which water flows under the usual conditions in a pipe of appreciable size and with appreciable velocity. These last cases are really the effect of sudden contraction or expansion taking place within a very limited distance.

Concluding Remarks.

The author had intended to devote the third section of the paper to an investigation by optical methods of the effect produced by a body moving through water at rest under circumstances which ensure stream-line motion, and also a modification of this for finding the manner in which a fluid starts into motion, and passes through an orifice or round an obstacle, the motion starting either impulsively or gradually.

The experimental means of doing this had already been tried with promising results, but it will take some time to carry out this work; and there are many other experimental matters which might have been enlarged upon in the previous section, but which have only been dealt with briefly.

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Summing up the general results, it may be said (1) that in the previous paper it was pointed out that, to show plane motion of water, colour bands, under the conditions required, were of no use, while air was found to give satisfactory results, and that, with air, a thin clear film, or border, on the surface of the solid over which water flowed was discovered to be present in all experiments; that (2) the attempt to investigate the nature of this film led to the use of thin sheets of water in which air itself was no longer of any use, but the colour bands became perfectly manageable, thus affording a final proof, as the author ventures to think, that his original theory as to the nature of this film was correct; (3) it having been found practicable to manipulate thin sheets of water, stream-line motion under these circumstances has been compared with the stream lines obtained by means of mathematical reasoning for the motion of a non-viscous fluid in two dimensions of space; (4) comparative results can thus be obtained for the two states of water separated by the critical velocity; (5) beyond this, stream lines have been obtained, directly, for numerous forms for which no mathematical solutions of the stream function have hitherto been given, or, indeed, seem possible, and which stream lines can apparently only be arrived at by the most ingenious, though difficult and laborious process, proposed and discussed in Mr. D. W. Taylor's paper on "Ship-shaped Stream Forms," the geometrical principles of which were first developed by Rankine and brought before this Institution in his paper "On Stream-line Surfaces" (Trans. I.N.A., Vol. XI.).

In the present paper no attempt has been made to investigate numerous questions which appear to offer material for further examination, viz., the effect of various pressures and velocities, the effect of the different thicknesses of the sheets in connection with velocity; the behaviour of fluids, other than water, having different viscosities; or to examine the critical velocity for the case of thin sheets under different circumstances.

Though the author feels there is no need to apologise for dealing almost entirely with theoretical questions, he would, in concluding, recall the words used by Mr. D. W. Taylor in the commencment of the paper, to which several references have already been made:—

"Doubtless the day will come when the naval architect, given the lines and speed of a ship, will be able to calculate the pressure and velocity of the water at every point of the immersed surface. That day is not yet, but the present state of our knowledge of the mechanics of fluid motion is such that we can determine completely, under certain conditions, the pressure and velocity in a perfect fluid flowing past bodies whose lines closely resemble those of actual ships."

The author would remark that, apart from the purely scientific aspect of the questions which have been raised in the present paper, the methods which he has

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employed enable a naval architect, by finding the correct stream-line forms experimentally for any section, at any rate, with plane motion, to determine the pressure and velocity at any point in relation to the immersed surface, and that this therefore realises, at any rate for one set of conditions, the anticipations which the author of the above paper has expressed.

APPENDIX I.

Stream Lines for the Fluid Flowing in a Canal of Width a Past a Centrally Placed Cylinder of Radius c.

The approximate value for the stream function for such a case is given by—

$$\frac{\psi}{u} = x - \frac{\pi c^2}{a} \frac{\sin \frac{2\pi x}{a}}{\cosh \frac{2\pi y}{a} - \cos \frac{2\pi x}{a}}$$

where a = width of canal, c = radius of cylinder, u = velocity of undisturbed flow, and the axis $o\,y$ is the direction of flow.

For the present purpose it is necessary to trace the stream lines for eleven equidistant values of ψ in one half of the canal, the other half being symmetrical about the axis $o\,y$.

The first stream line will coincide with the external portion of the axis $o\,y$, and with the boundary of the cylinder. The last or eleventh will coincide with the outer boundary of the canal or with the line—

$$x = \pm \frac{a}{2}.$$

Take as unit of length a = width of canal.

For convenience, make—

$$\frac{\pi c^2}{a} = \frac{1}{10}$$

or—

$$c = \cdot 1788,$$

the equation of the stream lines now becomes—

$$C = x - \frac{1}{10} \frac{\sin 2\pi x}{\cosh 2\pi y - \cos 2\pi x}.$$

It would be convenient, for purposes of plotting, to assume a value of y (say h), and giving C in succession, the equidistant values corresponding to the different stream lines, to solve for x, and so obtain the intersection of the different stream lines with the line parallel to $o\,x$, viz., $y = h$.

The direct solution of the equation in this manner is, however, practically impossible; but the following method of cross curves, as suggested by Mr. Riddlesworth, enables the result to be obtained in a most elegant manner. First assume $y = h$, and, giving x in succession the values ·1, ·2, ·3, ·4,

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solve for C. Then, plotting the values of x and C, as in the diagram, Fig. 20, Plate XI., we are able, by dividing the axis of C into a number of equal parts, 10 in this case, and projecting, to obtain the value of x corresponding to the equidistant values of C, *i.e.*, to the different stream lines.

We shall obtain the intersection of the nine intermediate stream lines with each of the lines $y = 0$, $y = \cdot1$, $y = \cdot2$, $y = \cdot3$, $y = \cdot4$, $y = \cdot5$.

The values of cosh $2\pi y$ as set out in the following table are required—

$2\pi y$.	Cosh $2\pi y$.
0	1
2π (·1)	1·204
2π (·2)	1·89
2π (·3)	3·37
2π (·4)	6·207
2π (·5)	11·15

For each (x, C) curve there will generally be obtained 6 points corresponding to $x = 0$, $x = \cdot1$, $x = \cdot2$, $x = \cdot3$, $x = \cdot4$, $x = \cdot5$; the exceptions occur when the line $y = h$ cuts the cylinder, and then the initial value of x is given by—

$$x = \sqrt{c^2 - h^2};$$

C being zero.

The following table contains trigonometrical values that are necessary for the work which follows :—

x.	$2\pi x$.	Sin $2\pi x$.	Cos $2\pi x$.
0	0	0	1
·1	·628 = 36°	·588	·809
·2	1·257 = 72°	·951	·309
·3	1·885 = 108°	·951	− ·309
·4	2·513 = 144°	·588	− ·809
·5	3·1416 = 180°	0	−1

The arithmetical operations for finding values of C are given by way of illustration in the case for which $y = 0$. The other results, which involve similar operations for each of the values of y, being given in a tabular form.

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I.—When $y = 0$, $\cosh 2\pi y = 1$;

$$\therefore C = x - \frac{1}{10}\frac{\sin 2\pi x}{1 - \cos 2\pi x}.$$

Now, the line $y = 0$ cuts the cylinder, and $\therefore$ the initial value of x (see *ante*)—

$$= \sqrt{c^2 - o^2} = c = \cdot 1788$$

(*a*) $x = \cdot 1788$, and $C = 0$ from the kinematical conditions.

(*c*) $x = \cdot 2$; then $C = \cdot 2 - \frac{1}{10}\frac{\sin 1\cdot 257}{1 - \cos 1\cdot 257} = \cdot 2 - \frac{\cdot 0951}{1 - \cdot 309} = \cdot 2 - \cdot 139 = \cdot 061.$

(*d*) $x = \cdot 3$; then $C = \cdot 3 - \frac{1}{10}\frac{\sin 1\cdot 885}{1 - \cos 1\cdot 885} = \cdot 3 - \frac{\cdot 0951}{1 + \cdot 309} = \cdot 3 - \cdot 0726 = \cdot 2274.$

(*e*) $x = \cdot 4$; then $C = \cdot 4 - \frac{1}{10}\frac{\sin 2\cdot 513}{1 - \cos 2\cdot 513} = \cdot 4 - \frac{\cdot 0588}{1 + \cdot 809} = \cdot 4 - \cdot 0325 = \cdot 3675.$

(*f*) $x = \cdot 5$; then $C = \cdot 5 - \frac{1}{10}\frac{\sin 3\cdot 1416}{1 - \cos 3\cdot 1416} = \cdot 5.$

VALUES OF C.

Values of x.	$y = 0$.	$y = \cdot 1$.	$y = \cdot 2$	$y = \cdot 3$.	$y = \cdot 4$.	$y = \cdot 5$.
$x = 0$			0	0	0	0
$x = \cdot 1$			·045	·077	·089	·094
$x = \cdot 2$	·061	·094	·140	·169	·184	·191
$x = \cdot 3$	·227	·237	·257	·274	·285	·291
$x = \cdot 4$	·368	·371	·380	·385	·391	·395
$x = \cdot 5$	·5	·5	·5	·5	·5	·5

The exceptional values are—

$x = 0$ $y = \cdot 1788.$ $C = 0$
$x = \cdot 1$ $y = \cdot 148.$ $C = 0$

From the foregoing table the cross curves shown — · — · — · — · , Fig. 20, Plate XI., have been drawn, and hence the stream lines found. From these stream lines the ordinates in Table I. were obtained which have been used for comparison with the experimental results of the identical case plotted on the lantern screen.

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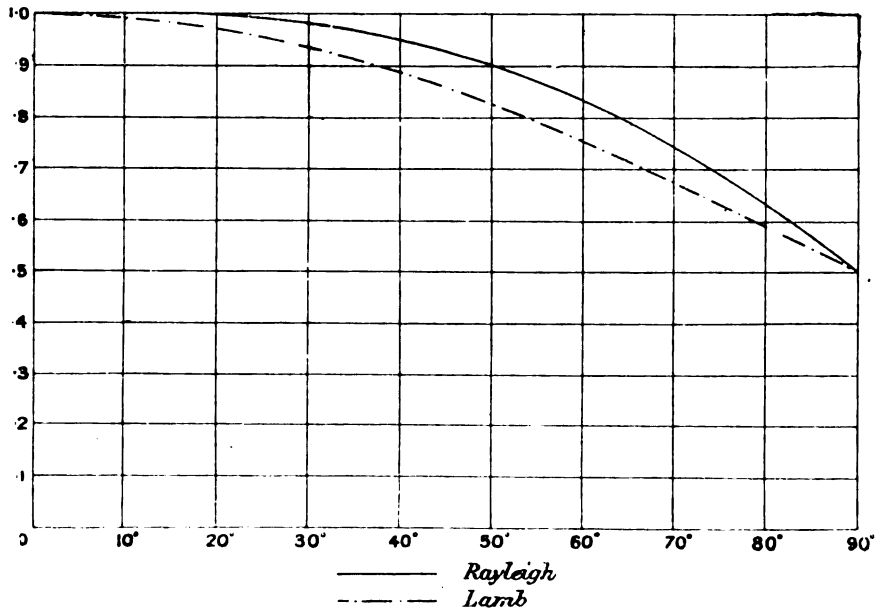
APPENDIX II.

COMPARISON OF LORD RAYLEIGH'S AND PROFESSOR LAMB'S FORMULÆ FOR THE POINT AT WHICH THE STREAM IMPINGING ON AN INCLINED FLAT PLATE DIVIDES (PP. 31 AND 32).



In the above diagram the full line (taken from Mr. D. W. Taylor's work on "The Resistance of Ships," page 16) gives the position of the point above referred to, using Lord Rayleigh's formula (quoted on page 32 *ante*), based on the hypothesis of a surface of discontinuity behind the plates.

The dash and dot line gives the position of the same point, using Professor Lamb's formula, (quoted on page 31 *ante*), appropriate to the case of continuous stream-line motion.

In both cases the length unity (1·0) represents the full width of plate, and the intersection of a vertical line through a point on the horizontal axis representing the angle, with either curve, gives the position on the plate at which the stream divides for the corresponding formula at that particular angle.

DISCUSSION.

Sir WILLIAM WHITE, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): Lord Hopetoun and Gentlemen, most of us remember the paper which Professor Hele-Shaw read at the International Congress last summer, and the beautiful experiments which he then showed as to the flow of water past solid bodies. Interested and charmed as we then were, we did not anticipate that he would, in the comparatively brief interval which has elapsed, have extended his methods and added to the value and beauty of his experiments to the extent he has since done. I read this paper carefully

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before the meeting, but, I am glad to say that the experimental illustrations which we have now had the opportunity of witnessing have tended to clear up, in my own mind, certain points where I required further explanation. In relation to the film of water close to the boundary of the solid body, one of the experiments which he has showed answered a question which I was going to ask. We then saw how the film became established as the flow of water proceeded. There is no doubt, as has been said by the author, that the question of frictional resistance demands that we should know more about the relative movement of the water in contact with, or very near to, the boundary of the solid body. The late Mr. Froude's experiments on that subject gave us information going far beyond anything which we previously had in precision and in value. But it is impossible to have to do with the propulsion of ships without realising the fact that, when one comes to deal with ship-shape forms and with ships of varying dimensions, we still feel a necessity for knowing more in regard to frictional resistance. In our model experiments on ship-shape forms, we keep close to the method which the late Mr. Froude devised; and, for designing purposes, there is no doubt the result has been satisfactory. We have been able to proceed with greater security in adopting new dimensions and forms, or in aiming at speeds that have not been previously attained. All the same, it must be admitted that, for exact scientific purposes, there has always been an element of doubt in regard to the "frictional correction" in passing from a model to a ship. Now, I do not think, so far, that doubt has been resolved, but I am convinced that, when by Professor Shaw's beautiful methods we can see and record, in a permanent form, what water is doing in flowing past a solid body, there is much greater hope of our getting exact and scientific results. We have been obliged to take facts in the aggregate, as it were, to a great extent. For scientific purposes we must resolve this problem into its several and independent parts. What the water is doing close to the skin of a ship I do not think any of us know. I remember being with Mr. Thornycroft many years ago in a torpedo-boat—I think it was in 1878. When that boat was running at high speed a hole was opened through her bottom. I put my finger through that hole. For a certain measurable distance of projection one did not feel any very great or violent pressure upon the tip of the finger, showing clearly that, at that place, at all events, the water in the immediate neighbourhood of the skin of the vessel had not any violent relative motion. A very small further projection of the finger made one feel as if his finger was being cut off against the edge of the hole. Mr. Thornycroft, on the same occasion, made experiments with a small tube by means of which we determined the limits of extension and direction in which that tube might be placed before water passed through it into the vessel. This experiment was made by Mr. Thornycroft because it had been stated that, in some of the operations during the Russo-Turkish war a Russian torpedo-boat had run home with a hole in her bottom, having been shot through. The fact was thus established that, in the immediate neighbourhood of the skin of the vessel there was very small relative motion between the water and the vessel. But, we want to know more respecting the relative rate of motion in different parts of the length and surface of the vessel, particularly in the entrance and in the run. With the aid of these beautiful colour bands, of which Professor Shaw has shown us specimens, and with the careful measurements which can be applied to them, we shall, no doubt, learn a great deal more about these variations in the velocity and pressure of water passing the ship. There is another aspect of the paper which deserves mention. As a student, I have attended the late Professor Rankine's lectures on stream-line motion. To-day, looking at these diagrams, experimentally produced, I was necessarily reminded of the diagrams which that wonderful man produced from purely mathematical investigation. Professor Shaw has shown us, for the case of a cylinder, that there is practical agreement between his experimental determinations and the mathematical construction. He goes on to say, and with perfect justice, that

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where purely mathematical treatment must fail then the experimental may come in. We have thus the promise of dealing with an endless variety of forms and obtaining, experimentally, results which must be closely approximate to the truth. That, if I may be allowed to say so, I regard as a wonderfully important step in advance. We are under the greatest obligation to Professor Shaw (and I would remind the Meeting that he is not a member of our Institution) for following up this line of research, and for keeping this Institution posted as to his latest results. I can assure him that, if he will only continue to give us the benefit of his inquiries, he will find the Institution of Naval Architects always grateful and always giving him the warmest welcome.

Sir NATHANIEL BARNABY, K.C.B. (Vice-President), here took the chair.

Mr. HENRY H. WEST (Member of Council): Mr. Chairman and Gentlemen, as Professor Hele-Shaw kindly invited me to see his experiments before he showed them to you, and has let me know, from time to time, what he has been doing, I may, perhaps, be excused for making a few remarks. I want to say, first, that I congratulate Dr. Hele-Shaw on the great advance he has made since he read his paper before the International Congress of Naval Architects last year. We must admit that, however interesting those experiments were, the stream-line form in them lacked distinctness. It appears to me that the very thing which made them visible was the thing which destroyed their perfectly clear character; we had rough approximations to stream-line forms, but they were disjointed. Although Professor Hele-Shaw says that the air in those experiments had no practical effect, I venture to think it had a very practical effect—that it broke up the lines; not only so, but its presence gave what we may call an unnatural elasticity to the water, which allowed local and accidental distortions of form to occur, which, of course, were projected upon the screen. Further, the very appreciable thickness of those early water films suggests, to my mind, that there might be different proportions of air and water in different parts of the thickness of the film, which would allow various distortions to be going on in different planes, the consequence of which was—Dr. Hele-Shaw will correct me if I am wrong—that the pictorial representations on the screen had a woolliness, and disjointed character, which was entirely different from what we have seen this afternoon. I think the idea was an extremely happy one of reducing the thickness of the films to extreme tenuity. Of course a channel of so small an area as that which Dr. Hele-Shaw has arrived at required considerable pressure to drive the water through it, but in this manner he got perfectly clear and defined colour bands. Unfortunately, the experiments this afternoon have not, by any means, been as perfect as Professor Shaw has them in his own laboratory, where he gets completely rid of the air, which at first was his friend, but now is his enemy. I think it was an exceedingly happy and scientific intuition in Professor Hele-Shaw's process, to obtain, practically, an unlimited breadth of channel by cutting out a lateral boundary to a true stream line for that particular form. But, if the experimental form were an ordinary ship-shaped body, and not one of the usual mathematical figures for which stream lines could be calculated, how would the Professor delineate his boundary line? If it involved, as it appears to me it would involve, calculation and plotting of what that boundary form would be, I am not quite sure that we might not almost as well plot down the whole of the stream lines instead of introducing this artificial boundary. Again, assuming that we adopt only an approximation for the form of the channel boundary, how are we to ascertain and eliminate the error? Another point worthy of remark in connection with these experiments is that, after all, they only give us what is taking place in a single plane out of an infinite number. As yet we have no light, at least no light that I know of, on the behaviour of a stream influenced by a contiguous stream. In a ship-shaped body adjoining films would meet different forms of obstruction,

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due to the varying form of the vessel, and thus streams, having different local velocities, would be in contact with one another. I should like to know how Dr. Hele-Shaw expects that those streams would act upon one another.

Professor HELE-SHAW: Do you mean different films in sheets—not sideways?

Mr. WEST: I mean, supposing you had an obstructing body of a substantial thickness, instead of the mere film which forms the obstructing body in your slide, and that body constantly varied in form, like a ship's form varies, no two contiguous planes in its depth having the same water-line shape, then, manifestly, the obstruction to the flow of water in each film would be of a different form to the one immediately in contact with it, and consequently, as it appears to me, you would have different local volocities for adjoining parts of contiguous films. The late Dr. Rankine said that the lines of flow on the skin of a ship would follow geodetic lines—in other words, riband lines. Anybody who has examined well-worn copper in its place on the bottom of a wooden ship, must have been struck by the apparent lines of wear, indicating that something very similar to this is the path of water upon the surface of the ship; and it appears to me from this that, not plane horizontal sections, but plane diagonal sections, would give us truer representations of what the actual stream lines were. Of course a riband line is not absolutely a diagonal, but it is, approximately, the trace of a symmetrical diagonal section. The interest of Dr. Hele-Shaw's experiments seems to be that he has succeeded now in depicting stream lines and maintaining them for such a length of time as to enable him to get a copy of them—a permanent record of them which he can investigate as much as he likes at his leisure. Further, he has examined some of those lines and compared them very closely with the theoretical determination of what those lines should be; and in the cases that he has investigated he finds a very close agreement which, presumably, would be the same for any other forms. I do not like detaining the meeting at this late hour, but I should like to say one word about Fig. 53 and Fig. 54, one of the slides that we saw this afternoon. It is this slide of contraction and expansion of the stream lines—enlarging the pipe, so to speak. When Dr. Hele-Shaw, a few days ago, showed me a very beautiful photograph of that, I asked him what was taking place in these two extreme corners. He said that, when he had reduced his water film to a very thin one, and had a sufficient pressure to drive the water through it, he positively got the line driving right into the corner, showing that, if there were any particle of water shirking its duty, or getting jostled by its more favoured neighbour into a corner, there was a line of police that compelled it to move on in perfect obedience to the law of stream-line flow. What practical result is to be the outcome of all this does not appear to be very clear; but that it throws an interesting light on an intricate study there can be no doubt. The narrowness, or broadness, of the band of colour denotes variations of pressure. That variation, I take it, is shown to us rather qualitatively than quantitatively, and until it can be given to us in numerical values, and, in addition to that, with a full knowledge, or, at any rate a very much fuller knowledge than we possess at present, of what are the conditions that vary those breadths, I am afraid that the application in practical design must be, we will say, postponed. There is just another point: the scale of these experiments is necessarily very small; but, assuming the value of accurately ascertaining stream-line form, I do not see myself why they should not be produced on a large scale and printed by the direct blue print process. You might have one of three or four feet instead of having a small thing five or six inches square. No doubt there are many difficulties, but Dr. Hele-Shaw has got over so many already that I am quite sure he could get over those. In conclusion, I wish to say what pleasure it has given me to hear my friend's paper, and to see his beautiful illustrations. I admire the scientific insight, the perseverance, and the manipulative skill

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with which he has brought these experiments to so great a success, and I hope that, by and by, he will succeed in giving us something that is of more direct practical application—it cannot be of more interest.

Mr. J. I. Thornycroft, F.R.S. (Vice-President): Gentlemen, I have very few words to say on this paper. What I have to say is a reference to the effect of air on the motion of the fluid. I think what Mr. West has told us with regard to it having a baneful influence, as it were, on the motion is quite true, and what I wish to call particular attention to is what Lord Kelvin told me on one occasion, when I was describing to him what I proposed to do to reduce the resistance of a special form of vessel. I proposed underneath the vessel to use air to reduce the resistance. That is not a new proposition, as you know, it has often been proposed, and I am not quite sure that, under certain conditions, it would not be favourable; but Lord Kelvin's opinion was that it could not be used with advantage. If you used a mixture of air and water underneath the vessel this would be a cause of great increase of resistance. I think the experiments brought before us by Dr. Hele-Shaw do show that there is truth in what Lord Kelvin said. If you watch the flow of fluid in these beautiful experiments you see in the motion of the mixture of air and water, especially in the curved tube, a sort of tendency for the air to aggregate. A great difference is seen between the behaviour of the mixture of air and the water and the homogeneous, or nearly homogeneous fluid, because, I take it, that the colouring matter did not alter the density of any part of those streams from the density of the other part sufficiently to have any appreciable effect. In experimenting with a mixture of air and water the tendency is for the difference of density to assert itself by the greater *vis viva* of one than of the other, and to change the velocity of the stream in different parts of its return. We must all greatly admire the experiments which have been brought before us.

Mr. J. Macfarlane Gray (Member of Council): Mr. Chairman and Gentlemen, were I to repeat every word of compliment spoken by the previous speakers I should still fall far short of expressing my high opinion of the paper of Dr. Hele-Shaw, and of the beautiful experiments he has put before us; therefore I shall say nothing more about that. I should like to express, however, what I have been thinking about the clear film which has been referred to several times in the paper. I should have been pleased had Mr. Thornycroft taken this up (I thought he was upon it), namely, that the flow of water must be the flow of least resistance. If there is a choice for it, it will choose that which has the least resistance, and if more water could get through it in the same time by letting air come to the side, no doubt that would be the way it would run; but it finds for itself that, lubricating the solid with the water solely, the shearing of the water offers less resistance than when mixed with air, and therefore, if once the water gets to the side it cannot again get away from it, because putting it away from it would be retarding the flow. It must be true, therefore—it tells you at once—that there is less resistance to water lubrication—wholly water—than with water and air. We are apt to think there is little molecular energy of translation in water as compared with air, but the velocity of motion of water, molecularly, is at least one hundred times the velocity of the swiftest steamship that ever floated upon it. The great specific heat of water in comparison to air shows that the molecular velocity of water is higher. That tends, no doubt, to diminish friction, because the energy is so great and the specific gravity so great, relatively to air, the consequently immense number of reversals of movement must facilitate translation. Therefore, I think that the experiment shows us that nature finds out its best lubricant. There is a great deal about water that we do not know, and do not even suspect. I remember twenty-four years ago I was in Chicago, and I was visiting a place where they made lead pipes by hydraulic pressure of two or three tons upon the square inch. They told me that,

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a few months before, there had been a leak of water from a joint—just a hair line—and one of the workmen stepped across it for a spanner to screw it up; the stream, or water hair, cut a femoral artery, and he was dead in a few seconds; it cut the flesh like a sword.

Mr. Archibald Denny (Member of Council): Gentlemen, I have no remarks to make by way of criticism, but what I wanted to suggest to Professor Hele-Shaw was that it would be extremely interesting to have the dimensions of the boats and obstructions he uses, and the velocity of the flow of water past them; that is the important thing for us to know in design, more especially in regard to the question of eddies behind square obstructions, and specially with regard to the struts of the propeller. My firm have done some work in that matter, but they have not come to any final conclusion. We have a difficulty in knowing whether the eddies follow the same law as, for instance, surface friction or wave-making. We believe eddy resistance does not follow the same law of proportion. I am sure Professor Hele-Shaw might manage to do something in that direction for us. I can only join with the other speakers in thanking Professor Hele-Shaw for his most able paper.

Professor H. S. Hele-Shaw, LL.D. (Visitor): I wish to thank Sir William White for the encouraging way in which he has spoken of the results of my present paper, especially as it was largely owing to his remarks on a previous occasion that I was led to continue the investigation. Mr. West has looked at the matter from the practical side, and as I believe he has come from Liverpool almost entirely for the sake of taking part in this discussion, I attach great weight to his remarks. I have not myself yet given much attention to the practical outcome of the experiments, because, apart from any other question, the theory of stream lines has played an important part in the mathematical treatment of fluids for a long time, and the most eminent naval architects have always studied the theory of the subject. Hence I have been content with trying to throw some light upon their actual nature. There is one remark of Mr. West, however, which leads me to mention a curious fact which I have observed, viz., the twist which takes place in the colour bands when the sheet of water is not very thin, although thin enough for the colour bands to remain fairly stable. This twist appears to be caused by the water in the middle of the sheet not having perfect stream-line motion, in the same way as the water close to the sides, and therefore, in passing the sharp edge of an obstacle, it is deflected by inertia to a position outside that which it should occupy upon the stream-line theory; different parts of the band are in this way influenced in a different manner, and the whole result is to give the band itself an actual twist in passing round a solid object. This shows how greatly the conditions of motion may vary within a very small distance, and points to the difficulty of making the experiments on the larger scale Mr. West suggests. As a matter of fact, I have tried a very much larger piece of apparatus than any of those exhibited, but any small variation in uniformity in the plate glass vitiates the whole result, and plate glass will have to be specially prepared for the purpose. The real use of the results, so far, seems to me to to be rather in the direction of confirming mathematical theories which are of the greatest importance, and the scale can always be enlarged for practical purposes of examination, as I have already shown upon the screen in this room. I am not quite able to follow Mr. Macfarlane Gray concerning the reason of the peculiar nature of the flow in the slides in which air is injected into the water. As I understand him, he explains the action on the general theory of least resistance. I have thought carefully over the matter, but have purposely avoided introducing unnecessary speculations in trying to account for the observed facts; it does, however, seem that the clear film may be partly accounted for as the result of inertia, which allows the heavier water to reach the side of the submerged body, and partly from the fact that, the velocity being less there, the pressure might be greater, and so the

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air be excluded from the portion where the water is moving with parallel motion; whereas, it is entangled and broken up in the portion where the sinuous motion of the water occurs. I thought Mr. Thornycroft would have mentioned in the discussion what he told me a little time ago, concerning the direction of a stream upon an inclined plate. He remarked that it was curious that the same thing occurred, almost exactly, on a screw propeller. Messrs. Froude and Brunel found that a line was formed on the surface of the blade of a screw propeller where the water divides, and this line is perfectly marked on the propeller after it has been in operation some time. I would conclude with one further remark concerning what Mr. Sydney Barnaby told me with reference to the lines of the torpedo-boat as compared with those of the dolphin shown in Figs. 41 and 42. These lines appeared to be absolutely identical, with the curious difference that their position is reversed. Now, the essential difference between the two is that the dolphin is entirely submerged, whilst the torpedo-boat moves at the surface; the wave-making resistance of the fish must bear a very small proportion to the total resistance compared with the wave-making resistance of the torpedo-boat, which becomes a most important factor in the resistance at high velocities. Hence, the difference between the two cases seems to be clearly illustrated by comparing the diagrams of the screw shaft strut, according as thick or thin sheets of water are used, the thick sheet of water representing the case of the submerged fish, in which the fine run of the stern is of the greatest importance in avoiding eddies, whereas the question of wave formation must be studied from the stream-line diagram, which it is possible, at very high speeds, may involve quite different considerations in the case of a body only partly submerged.

The CHAIRMAN (Sir Nathaniel Barnaby, K.C.B., Vice-President): Gentlemen, I am sure that, in giving our thanks, I shall represent the feelings of all here in saying, as has been said several times by the speakers, that we are greatly indebted to Dr. Hele-Shaw for his second paper. I trust he feels that we have done some little justice to his labours, that the speakers have really entered into the spirit of them, and that he may have been helped by some of the things which have been said and suggested here to-day. I trust we may meet him again, and that we may be mutually helpful to each other when we do so meet. In your name I give him your hearty thanks.

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HORSE-POWER ABSORBED BY SKIN FRICTION AND WAVE-MAKING IN SHIPS OF DIFFERENT FORMS AND PROPORTIONS DEDUCED FROM PROGRESSIVE TRIALS.

By James Hamilton, Esq., Member of Council.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 31, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

My Lord and Gentlemen, I have for a long time cherished the hope that some member of this Institution, or of a similar institution, who had a tank at his disposal—some modern Beaufoy—would give us the results of a series of experiments in which would be traced the gradual increase of resistance caused by successive additions to breadth in similar forms, beginning with a form of small proportionate breadth to length, and ending up with the resistance of the same form when driven broadside on; or would tabulate for us the varying resistances, due to filling out the ends, in vessels, or forms, of given common beam, or give the resistance as it changes with variations of draught.

In the absence of any such demonstration of the laws on which the wave-making resistances of models depend, I have attempted to deduce, from the progressive trials of actual vessels, the general principles governing wave-making resistance, and hope that the statement of the results arrived at, even if imperfect, may be of use to some of our members, or, may pave the way for some abler investigator of this subject—a subject giving daily concern to many, and one of the most fascinating to pursue.

In the course of the twenty years during which progressive trials have been made, one has had experience with a variety of forms, and one has learnt to choose data of equal trustworthiness for a given purpose. Those of us who have much to do with the analysing of trial-trip data know of the little corrections that have to be made here and there, even when the trial trips are conducted solely in the interests of science. The trials of different ships may be equally reliable, but not comparable. It is well known to the initiated that, because of the specified and insurmountable conditions as to the speed for which the propeller is to be adapted, or for other reasons, the power of the horse may even vary. This was well known to a countryman of ours. Speaking twenty years ago of one of his steamers, engined with compound engines by an engineer whose great forte lay in running up the horse-power, by the means

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of excessively small pitch and surface propeller, to bring out the result of 1½ lbs. of coal per indicated horse-power, and which ship had made a slow passage, in wrath he exclaimed: "What does it matter to me, if he burns more coal on the voyage, whether his horses are Clydesdales or ponies!" Keeping this in view, I have selected trials of a variety of different types which are comparable, and from these have deduced formulæ, more or less imperfect, no doubt, but which seem to be, on the whole, fairly satisfactory. Whether sufficiently accurate to be more than simply useful in clearing one's idea as to the relative proportions of skin friction, wave-making and propeller waste, for a given speed and form, may be judged by the results.

To enable broad comparisons to be made, speeds considerable in proportion to the lengths of the ships have to be taken. I have taken the speeds always as the square roots of the lengths. This is moderate; for a cruiser or other fast vessel represents the top speed for the aristocrats of the mercantile fleet, and something never attained to by any of the bluff or box-shaped type, useful as they are in their way, with the single and unique exception of the Imperial Russian yacht *Livadia*. This latter is the one example of a bluff ship being purposely fitted with powerful machinery to drive her at a speed far in excess of that for which her form was adapted. A comparison with this ship will be instructive, and, with regard to other full vessels, one can see with fair accuracy whether, or not, the principles when applied give a horse-power at this high speed in agreement with the horse-power at the lower speed within the capabilities of the vessels.

To give a correct idea of the types made use of, each ship has been brought to a length of 270 ft., and the derived particulars are given in the following Table I., and the derived speed curves in Fig. 1, Plate XVIII.

The indicated horse-power for each at this speed = to the $\sqrt{L}$, or 16·43 knots, is split up into:—

(1) *Initial engine friction.*—For engines about the size dealt with, taken as 4 per cent. of the total power.

(2) *Load engine friction* as 7·2 per cent. of the total indicated horse-power, or 8 per cent. of the sum of wave-making, skin friction, and propeller waste indicated horse-power.

(3) *Propeller waste*, or all forms of loss incidental to the imperfection of propellers and their positions, and amounting to the difference between the power delivered through the shafting and the sum of the two following components (4) and (5), or power to overcome the tow-rope resistance. Taken for this purpose, the same as found from Mr. D. W. Taylor's curves of distribution of horse-power for the *Yorktown* at the speed

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$= \sqrt{L}$, or 31 per cent. of the total indicated horse-power, or 51 per cent. of the sum of the skin friction and wave-making indicated horse-power.

(4) *Skin friction* indicated horse-power, as calculated from the wetted surface, on the assumption that a resistance of one pound at a speed of one knot absorbes ·0030707 horse-power, as also given by Mr. Taylor, and that the resistance varies as $V^{1·83}$, and according to a co-efficient of friction (Table II.) depending on the length of the ship. Wet surface—

Bottom = L × B × co-efficient of fineness.
Sides = L × draught × 2.
Indicated Horse-power = W S × co-efficient $V^{1·83}$ × ·0030707 V
= W S × co-efficient × ·0030707 $V^{2·83}$.

TABLE I.

Derived Ships of Length 270 Feet.

		R	P	Y	S	M	O
1.	Length	270	270	270	270	270	270
2.	Breadth	30·94	41·16	42·92	31·50	33·58	30·94
3.	Draught moulded	11·22	14·29	16·51	9·64	12·91	12·89
4.	Displacement	1,179	2,159	2,865	1,189	1,955	1,848
5.	Co-efficient of fineness	·441	·476	·524	·508	·585	·601
6.	Speed = $\sqrt{L}$	16·43	16·43	16·43	16·43	16·43	16·43
7.	I.H.P.	2,250	3,200	4,305	2,414	3,467	3,330
8.	I.H.P. Initial engine friction 4 per cent.	90	128	172	96	138	133
9	,, Load engine ,, 7·2 per cent.	162	230	309	173	259	233
10.	,, Propeller waste 31 per cent. ...	697	992	1,334	748	1,198	1,032
11.	,, Skin friction (calculated) ...	765	1,025	1,179	745	970	940
12.	,, Balance wave-making of actual derived ship	536	825	1,311	652	902	992
13.	I.H.P. by Formula — Calculated wave-making of standard ships of co-efficient ·5 ...	650	1,038	1,200	608	784	723
14.	I.H.P. by Formula — Correction for difference of co-efficient	−72	−68	+102	+26	+240	+278
15.	I.H.P. by Formula — Calculated wave-making of actual derived ship	578	970	1,302	634	1,024	1,001

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(5) *Wave-making* indicated horse-power is what remains, after deducting (1), (2), (3), (4) from the total horse-power.

For convenience I copy down here part of a table giving co-efficients of friction:—

TABLE II.

SURFACE FRICTION CO-EFFICIENTS.

Length of Ship.	Iron Bottom Clean and Well Painted.	Copper or Zinc Sheathed.	
		Sheathing Smooth.	Sheathing Rough.
200	·00944	·00943	·01170
250	·00933	·00936	·01160
300	·00923	·00930	·01152
350	·00916	·00927	·01145
400	·00910	·00926	·01140
450	·00906	·00926	·01137
500	·00904	·00926	·01136

Having found the indicated horse-power absorbed by wave-making, as set out on line 12 in Table I. for each type, I have attempted to find out the principles involved by accounting, in the first place, for the differences found in vessels of the same form in the sense of having the same, or about the same, co-efficient of fineness, and of having the lengths of entrance and run approximately the same, but in which the beams differ, and consequently the angles of entrance and run also differ.

The simplest form of this is a vessel with a co-efficient of fineness of ·5, which may be said to be all entrance and run.

I call this the *standard form*, and in each case start from this, finding the horse-power by the following formula:—

$$\text{Indicated horse-power} = \frac{V^n D^{\frac{5}{2}}}{700};$$

where—

$$n = 2{\cdot}83 + \frac{B}{L},$$

L = length between perpendiculars,

B = the full extreme moulded breadth of the ship.

The figures are given on line 13 of Table I.

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The second step is to make the necessary correction for displacement added on to the *standard form*, or for displacement deducted therefrom; that is to say, having got the indicated horse-power for a vessel of the breadth required, but with a displacement corresponding to a co-efficient of fineness of ·5, to find, in the second place, the additional indicated horse-power required by the addition of the displacement necessary to produce the form of the ship required; or, conversely, to find how much indicated horse-power falls to be deducted due to the displacement being under that of the standard ship. The formula for this correction is arrived at by comparing the indicated horse-power belonging to each of the types in Table I. for wave-making, after allowing for the indicated horse-power due to the *standard form*, and is found to be—

$$\text{Correction for form indicated horse-power} = \frac{V^n . d^{\frac{2}{3}}}{800} ;$$

where—

$$n = 2{\cdot}83 + 2\,(\text{co-efficient} - {\cdot}5),$$

or where—

$$n = 2{\cdot}83 - 2\,({\cdot}5 - \text{co-efficient}) ;$$

$d^{\frac{2}{3}}$ is the $D^{\frac{2}{3}}$ of the excess or deficient displacement compared with the standard form displacement. The figures for this correction are given on line 14, Table I.

The calculated total indicated horse-power for wave-making on these principles is given in Table I. for each type, line 15, and the agreement, more or less accurate, with the figures found by splitting up the actual or derived indicated horse-power into its components, line 12, can be easily seen. It would be absurd to expect too close an agreement, keeping in view the many small things that enter into the question of the efficiency of steam vessels, including the method of driving the feed and circulating pumps; all that we can look for is to get a general idea of the principles governing wave-making.

Many interesting comparisons may be made between the figures given in Table I. I will only draw attention to one between the *Phaeton* and *Yorktown*, both of which are broad deep ships, but one much finer than the other. It will be seen that the indicated horse-power for a standard ship of the *Yorktown* breadth and draught is only slightly greater than for the standard ship of the *Phaeton* form, due to a small increase to breadth and draught, whereas the indicated horse-power due to the difference between a co-efficient of fineness of ·53 and ·476 is represented by 102 being added in one case and 68 deducted in the other.

There is good reason for believing that the percentages of the total indicated horse-power representing propeller waste and load friction are less in high-powered vessels than in low-powered, apart from the fact that, in high-powered vessels a larger proportion of power goes through the propeller, separate engines being used for feed and circulating pumps, &c.; and, in passing to the larger fast vessels, one must make

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the necessary correction based upon experience; but it will not be far out to take the *Yorktown's* percentage of waste for vessels with machinery about the size given in

TABLE III.

CALCULATED INDICATED HORSE-POWER FOR VESSELS OF DIFFERENT FORM BY FORMULÆ.

	A	B	C	D	E	F
1. Length	240	300	350	345	300	260
2. Breadth	29·83	37	44	43·77	39·5	37
3. Draught moulded	10·1	16·58	17·66	16·37	19·85	17·29
4. Displacement	1,114	3,125	4,922	4,910	5,196	3,820
5. Co-efficient	·539	·594	·633	·695	·773	·804
6. Speed = $\sqrt{L}$	15·49	17·32	18·71	18·57	17·32	16·12
7. Wave-making, *standard*... ...	478	1,237	2,030	1,870	1,494	986
8. Correction for form	+ 64	+ 427	+ 1,087	+ 1,890	+ 2,845	+ 2,209
9. Total wave I.H.P.	542	1,664	3,117	3,760	4,339	3,195
10. Skin friction	582	1,499	2,476	2,389	2,327	1,251
11. Propeller waste 51 per cent....	573	1,613	2,852	3,135	3,400	2,267
12. Load engine friction 8 per cent.	136	382	675	·743	805	537
13. Initial engine friction 4 per cent.	73	206	365	400	435	290
14. Total I.H.P.	1,906	5,364	9,485	10,427	11,306	7,540
15. I.H.P. for 1 knot less than above, H.P. varying as the power n for standard ship + $\frac{\text{Excess I.H.P.}}{\text{Standard I.H.P.}}$	1,522	4,400	7,831	8,374	8,465	5,400
16. n or power of speed = ...	3·08	3·30	3·49	3·96	4·87	5·21

Table I., and, applying the formulæ to some fuller types of vessels, to put them to a further test by seeing how the horse-power agrees with the known results, and at

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the same time illustrate the price that has to be paid for driving vessels at speeds in excess of those for which their forms and proportions are adapted.

Table III. gives particulars, and Fig. 2, Plate XVIII., represents the curves of speed and power for several vessels of different forms and of different sizes, as tried progressively. The spots enclosed by circles represent the total indicated horse-power as calculated by the formulæ given in this paper, at speeds equal in each case to the square root of the length (line 14, Table III.). There is an agreement with the speeds and horse-power, actually attained on the trials, which seems to show that the formulæ represent in a general manner the principles governing wave-making.

The spots with double circles round them have been found by applying the principle that for speeds at or about the $\sqrt{L}$, the total horse-power will vary with a power of the speed depending on the power of the speed at which the wave-making indicated horse-power of the standard vessel varies, and on the ratio that the correction for form indicated horse-power bears to the standard ship indicated horse-power, or as V^n; where—

$$n = n \text{ for standard} + \frac{\text{correction for form I.H.P.}}{\text{standard I.H.P.}};$$

or where—

$$n = n \text{ for standard} - \frac{\text{correction for form I.H.P.}}{\text{standard I.H.P.}};$$

The figures are given in Table III., line 15, and the powers at which the indicated horse-power varies in line 16.

On the face of it, it is obvious that this can only be a rough approximation; but if used within limits, along with the formulæ given above, the indicated horse-power for a given vessel may be predicted to a nearness without reference to other ships at speeds near to the $\sqrt{L}$, or more or less approximately at other speeds, and may prove useful. In any case the method seems to be sufficiently accurate to be used for illustrating the value of a good form, both in regard to smallness of beam and in regard to a fine co-efficient of fineness in connection with a small expenditure of indicated horse-power. At the moderate speeds—equal to the $\sqrt{L}$—form is everything—the average vessel considered.

As a good example of the application of the formulæ above referred to, carried to the utmost extreme, it may be interesting to state that the *Livadia* would require 11,000 I.H.P. The prolongation of her power and speed curve indicates this at 15·13 knots = $\sqrt{L}$.

To take a more exaggerated case, if propelled broadside on, the formulæ would give—

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Standard wave-making	41,630
Correction for form...	600
Total wave-making...	42,230
Skin surface...	1,620
Propeller waste	22,380
Load-engine friction	5,296
Initial engine friction	2,860
Total indicated horse-power	74,386

The wave-making I.H.P. is varying in this case at the 4·33 power of the speed.

The vessels in Table III. would, if driven broadside on, require for wave-making, horse-power calculated at powers of the speed ranging from 9·8 to 10·9, which, with the large addition of propeller waste, load and initial friction, would become practically infinite, while at the same time no change has taken place in the volumes of displacement or in the amounts of skin friction I.H.P.

Whether one uses, for the prediction of horse-power, the old Admiralty formula in connection with the speed curve of a nearly similar vessel, and, with nice judgment, varies the constant to cover the slight differences of form and proportion, in the same delicate manner as the astronomer does when, after focussing his telescope by the quick gear, he applies the small wheel for the finer adjustment, or whether one applies other methods, the full appreciation of the relative values of the components that make up the total indicated horse-power must always be useful, and I trust that the present imperfect contribution to the subject may not be taken amiss.

DISCUSSION.

Mr. R. E. Froude, F.R.S. (Associate Member of Council): My Lord, I have very few words to say on this paper, because I had not seen it before I came into the room, and I cannot feel at all sure that I have mastered the details of the principle which Mr. Hamilton is going upon, and I should be very sorry to criticise his method on imperfect information. Another thing is this: that, in the considerations of the same character which I have to do with, we have, of course, such extremely different data to go upon that I am not habituated to framing the subject in the same form as Mr. Hamilton necessarily has to adopt. I hope that those gentlemen (of whom there are several present) who are in the same position as Mr. Hamilton, and have to guide themselves by the same sort of experience, will state how they deal with the same problems. I can only say that I am exceedingly glad to find that practical shipbuilders are in the habit of dealing with all their information on such a scientific system as Mr. Hamilton has adopted.

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Mr. Archibald Denny (Member of Council): My Lord and Gentlemen, I perhaps occupy an intermediate position between Mr. Froude and Mr. Hamilton, for my firm possess a tank, and we are also accustomed to deal with data clear of the tank, as Mr. Hamilton has done. Before saying anything on the paper, I would like to emphasise what Mr. Froude has said, that it is not possible to discuss a paper like this put into one's hands five minutes before one is asked to speak upon it. I am sure Mr. Hamilton will not object if I use him as an object-lesson. I have been insisting, in season and out of season, at our Council meetings, that it is desirable that we should get all the papers a week or ten days before we come here. We now, through the energy of the Secretary, do get the majority of the papers before the meetings, and we know what a great benefit it is. With regard to the methods adopted by Mr. Hamilton, I think, without going into detail at the moment, that he is adopting a good and scientific basis for examining the data at his disposal. As to whether his assumptions are all correct I am not prepared to say, and also with regard to the question of the propeller waste I cannot say I quite agree with him. May I also make a personal reference in regard to the skin friction. At Southampton I read a paper giving a more accurate method of calculating the wetted surface, and I think, if I remember rightly, the surface of the sides was obtained by using 1·7 as the multiplier instead of 2. It makes no difference to Mr. Hamilton's methods; but, if he is going to use a formula, it may as well be as nearly correct as possible. Mr. Hamilton brings all the speeds to one common measure, based on Froude's law, and that is certainly a step in the right direction. Had the paper been in our hands sooner, all of us who have progressive trial data at our disposal would immediately have applied these formulæ to their data to see how they fitted, so that the Institution is losing in this discussion much valuable information which, otherwise, it might have been possessed of; because, unless another paper is read next year on a similar subject, one has very little opportunity of giving the data. I congratulate Mr. Hamilton on having hit so nearly by his formulæ the actual power required in each case. (For further remarks by Mr. Denny, see p. 60.—Ed.)

Sir William White, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): My Lord and Gentlemen, it is always interesting to find a member of this Institution coming forward and giving us the benefit of the methods which he is accustomed to use in his professional work. That is particularly true in regard to the important question of the estimate of power for speed. Mr. Hamilton, in this matter, is following on the lines which his late partner, Mr. Kirk, traversed many years ago when he put before us his method of analysis, backed up by a very large number of examples of its application. I have had the opportunity of merely glancing through this paper. Like Mr. Denny I got it rather late, as we all must, but then Mr. Hamilton had not the opportunity of getting his paper finished sooner, and we had to choose between waiting a year or having it with the necessity for a somewhat imperfect discussion. Perhaps I may make a suggestion to meet the difficulty. The methods of the Institution permit additions to be made to the discussion, subject to the approval of the House Committee, and I sincerely hope that Mr. Denny, and perhaps others interested in this matter, will apply Mr. Hamilton's formula to their typical cases, and append to the remarks that have now been made examples of its working. That is quite in keeping with the rules of the Institution, and will prevent this very interesting paper from suffering so much as it otherwise would have done from its late presentation. In Admiralty practice, as Mr. Froude has said, we have the great advantage of our model experimental establishments. But, having had to work outside the Admiralty, where I had not an experimental tank, I, in common with many others, have at various times endeavoured to use progressive trials, as large scale model experiments, for future guidance, and, therefore, can better appreciate Mr. Hamilton's method. I began by saying that I have only had a short time to look

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through this paper, but I am probably not wrong in assuming that Mr. Hamilton, in the table on page 49, and throughout the paper, is working on certain assumptions as to the losses for initial engine friction and for load engine friction. May I ask if that is correct?

Mr. HAMILTON: Yes.

Sir WILLIAM WHITE: The total losses from those causes when applied to the maximum horse-power are assumed, I think, by Mr. Hamilton to be 11·2 per cent.

Mr. HAMILTON: For initial engine friction and load engine friction, yes.

Sir WILLIAM WHITE: I think that is an under-estimate. If it were not an under-estimate there would be a tacit assumption that the "co-efficient of propulsion"—the ratio of the effective to the indicated horse-power—would be extraordinarily high. So far as my analysis of trials has gone—and it has been pretty extensive—it would apparently be nearer the truth to assume that those two causes would reach as high as 15 per cent., in association with a propeller waste of 31 per cent. Otherwise we should have an efficiency which certainly is not ordinarily attained when we compare model experiments with steam trials. I do not know upon what experience this valuation of the 4 per cent. for initial friction rests. If it rests upon the late Mr. Froude's method of analysis applied to progressive trials, then I should say, from my own personal investigations, that is not a very sound position. With all the care that can be applied to actual trials in running down the curves of thrust towards their origin, the results obtained are not trustworthy. In this respect I am confirmed by the experience of many others who have tested the method. It was most attractive and most promising; but in practice it has not given results which can be accepted, or which have fixed a standard. If that is so, an adjustment of the figures given by Mr. Hamilton would be necessary. My own conclusion, resting on a large number of analyses, is that, with a waste on the propeller of from 30 to 35 per cent., the dead-load friction might vary from 5 to 9 per cent., and the working load friction from 7 to 8 per cent. The delivery of power to the propellers would, therefore, not be likely to exceed 80 to 85 per cent. of the indicated horse-power. These are simply corrections, or possible corrections, and they do not touch the method of procedure that Mr. Hamilton has adopted. As an empirical and practical method of approximating the horse-power in new designs I think Mr. Hamilton has placed us under great obligations by giving us the result of his years of work and his known interest in this subject.

Mr. JOHN INGLIS, LL.D. (Member of Council): My Lord, I am suffering under the same disability as Mr. Froude, Sir William White, and others. I only had the opportunity of reading this paper in a hansom cab as I was coming to the meeting. We certainly should be much obliged to Mr. Hamilton for anything he can do to simplify, or assist in, the calculation of speed. We have not the advantage, like the constructors at the Admiralty, of a considerable time to prepare a design before the ship is actually put in hand to be built. We have often to make up our minds as to what can be done in a very short time, and back our opinions with considerable sums of money. These investigations may be very useful. One never knows into what dark corner some light may be thrown. The suggestion that Sir William White has made as to supplementing this discussion by sending particulars from other trials is one which I should be glad to adopt. There is one question I should like to put to Mr. Hamilton. He says on page 53, "At the moderate speeds—equal to the $\sqrt{L}$—form is everything." If I do not mistake his meaning, the speed here being adapted to the length, the difference in dimensions is eliminated altogether, the ships are practically of the same

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size, and there cannot be any other difference between them than the difference of form. Perhaps Mr. Hamilton will explain that? I have found in my own investigations that, within ordinary limits of practice, size is of a great deal more importance than form—within the limits of form generally adopted, and within the moderate limits of speed in use in the Mercantile Marine. I had occasion once to attempt to explain to a shipowner how it was that cargo could be more economically carried in a ship of 12,000 tons displacement than in one of 1,200 tons. He seemed to think that the economy of the larger vessel was due to some great merit in her design; but, as I happened to be in some measure responsible for the design of the smaller one, I had an object in showing that the one form was as good as the other. I got a great deal of information from friends as to the performances of vessels of different sizes, I even went so far down as a steam launch 60 ft. long, and I found that, at 14 knots, the smallest vessel of the series took twenty-four times as much power as the largest per ton of displacement. I laid down the results at a single speed (14 knots) on a diagram, taking, as abscissæ, the lengths, and, as ordinates, the horse-power divided by the displacement. Putting down spots for all these ships, ranging from 60 ft. in length to 420 ft., I found that a very narrow strip indeed embraced all the results even from ships of considerable diversity of form. I shall be glad to send a copy of that diagram to the Secretary (see Fig. 1, Plate XIX.).

Mr. J. Macfarlane Gray (Member of Council): My Lord, I am not prepared to discuss this paper, not having had time to go into it. The late Dr. Froude, in a paper in the Transactions for 1876, at page 170, gives a geometrical problem which is useful in such a paper as this, and has been sometimes set by me in the examination paper for the Extra Certificate, and, on such occasions, has never been solved except by the use of logarithms. Thinking, therefore, that it must be but little known practically I reproduce it. When a portion of a curve has to be drawn whose equation is—

$$y = x^n$$

y being, say, horse-power, and x the speed of the ship, and two points (see Fig. 2, Plate XIX.), O the origin and A a point in the curve, are given, the tangent and the curve, at any point A, can be drawn by setting off $OB = (n - 1)\, y$ and drawing AB. If AC is then taken as a portion of the curve, set off $BD = (n - 1)\, EF$, and continue the curve approximately by drawing DC produced. This must be all well known, but I have not found it to be as much used as it might be.

Professor J. H. Biles (Member of Council): My Lord and Gentlemen, I think the information and the formula which Mr. Hamilton has given us are likely to be of value, perhaps not directly, but indirectly, in bringing out the possibility of reducing to an approximation, sufficient for practical purposes, the results of progressive trials in a form which makes them directly applicable for estimating purposes. That is the essence and the object of this paper, I think. The direction which Mr. Hamilton has taken to put his formula into shape is that he takes account of two things, ratio of length and breadth and the co-efficient of fineness. Those are the two varying things which he takes account of in the formula. Now, I think, while those two variations open up a large field, they do not, of course, and are not likely to, and are not expected to cover the whole of the ground. Variations in length and draught, or beam and draught, will necessarily affect resistance, and consequently horse-power, and therefore, before a complete solution can be obtained, or one that is completely satisfactory, the ratio of draught to length should be taken into account, I think. The question of taking fulness into account in the way in which Mr. Hamilton has done it is, of course, applicable within limits, and is intended only to be applicable within comparatively small limits, and I suppose that Mr. Hamilton

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would not think of applying it to a block co-efficient of 1, which would be a square block. Perhaps he will tell us whether he intends it to apply to limits of that kind. Those two things, the variation of the ratio of breadth and length and the fulness, are the basis of the assumption upon which Mr. Hamilton has built this formula. Now, I think it is within your knowledge, and, of course, it must be remembered in connection with this formula, that an increase of breadth in relation to length does not necessarily increase the resistance. There are many cases on record, and they are constantly occurring in tank work, I am sure, where an increase of beam is accompanied by a decrease of resistance. The question of fulness also is one that has the same kind of limitation. It does not necessarily follow that an increase of fulness upon a given form means an increase of resistance on account of form. Mr. Denny once very kindly took out some figures for me from tank experiments, plotting resistances for given displacements in terms of block co-efficients and at a considerable speed, the varying element in it being form. The form was taken haphazard, I think, and the extreme peculiarity of the curve, or rather the plotting, was remarkable. Supposing the left-hand ordinate (Fig. 3, Plate XIX.) represents a block co-efficient of ·4, and the right-hand ordinate represents a block co-efficient of ·6, then the resistances varied in all manner of ways, quite independently, apparently, of the block co-efficient, and, of course, the variation of resistance was due to the variation of form, so that the question of block co-efficient alone will, of course, not anything like completely cover the ground. I thought it might be of interest just to point out the necessity of guarding against interpreting these results too freely; but this does not in any way detract from the real value of the paper, because the real value of the paper is that it gives us a basis for investigation and comparison which is, certainly, a great deal nearer than anything we have had before of the same character. I should like if Mr. Hamilton would tell us whether the indicated horse-power in Table I., line 7, has been in any way corrected for initial engine friction, or whether all the horse-powers given there are horse-powers involving the ordinary proportion of engine friction to the maximum indicated horse-powers; or whether these are cut off directly from a speed curve and, therefore, have variations in themselves from their position on the speed curve due to engine friction varying directly as the speed. I think Mr. Hamilton understands what I mean, and perhaps he would make that point quite clear; because, if the basis of indicated horse-power given in that line 7 has not been corrected in that way, the comparison with a uniform proportion of engine friction of 4 per cent. would not be quite so close as it might be made. The information that Sir William White was good enough to give us of the percentage of dead-load and live-load friction of an engine I think is of extreme value. Those who have been attempting to find this out will be very grateful to him for it. I hope at some time we may receive from him, or from the Admiralty, some statement, or paper, showing us how the dead-load friction and the live-load friction have been and can be obtained in the ships of which the Admiralty have built so many. The difficulty that those who only try ships on the measured mile have is, as Sir William White pointed out, that the lower point of the indicated thrust curve is unreliable, and, further than that, the engine is doing work which is not a normal state of work. The engine friction, when the engine is running at low speed developing low power, is different to what it is when developing full power, and the same applies to live-load friction, when the conditions of the engine are changed, and the friction may possibly change, so that the results obtained on trials from low speeds are not anything like so reliable as one would like to have them. It seems to me that even the results obtained in the ship, which is a fair check in some cases, by running very light at full speed, are not a very good guide; because there again, although the engine is running at a speed more like the full speed, the amount of power going through it is very small, the heat conditions of the engine are very different, and the result cannot be depended upon. I do not know

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whether Mr. Froude can tell us about the turbine dynamometer, and some of the results of putting the full power of the engines through and getting what is the real power in that way. That is somewhat apart from Mr. Hamilton's paper, but Sir William White's remarks have led me to express a hope that, some day, we may have results of this kind.

Mr. JAMES HAMILTON (Member of Council): My Lord, I must really apologise to the gentlemen who have been kind enough to criticise my paper, for the fact that they had not the paper in their hands before midnight last night. That was due to no fault of Mr. Holmes—it was entirely my own fault. You will see there is a good deal of figuring in the paper, and a good deal of checking had to be done, and indeed I started it rather late. I find myself in the same position as these gentlemen are in, having to stand up and criticise their criticisms on such short notice. With reference to what Sir William White has said about the propeller waste and initial and load friction, I may say that I quite agree with Sir William that, more or less, the results will depend upon the correctness of these percentages—they are very large percentages, of course—and all I can say is, I have taken them from very careful trials of the *Yorktown*, as given in Mr. Taylor's book, and where he splits up the total horse-power into different divisions. I have taken them at the speed equal to the square root of the length, measured as carefully as possible from his curves. They may be, more or less, out; but I do not think it would affect the general principle to any very large extent. I can only say that, if any of the members will continue the discussion by reading papers, or applying the formulæ to ships that they may have tried progressively, it will be most interesting to me, and perhaps more daylight will be thrown upon the subject. Dr. Inglis asked me to explain the remark I make on page 53, that "form is everything, the average vessel considered." It is quite true that this comes in in connection with the part of the subject which deals with different sizes of ships; but, I may say I had no intention of saying that size was nothing. What I mean is that form is everything for easy propulsion in contradistinction to skin friction. I am sorry I had not the benefit of Dr. Froude's diagram in preparing my paper. It might have shortened one's labours considerably. Professor Biles has quite truly said that what I have dealt with here is the ratio of breadth to length, and also the co-efficient; in other words, I have dealt with the bulk and the form. There are two kinds of form. Professor Biles, if I understood him, says that an increase to beam does not necessarily carry with it an increase to resistance, but form comes into play, and co-efficients of fineness come into play. My view of it is that it does, if you start with a form of this description (line A, Fig. 4, Plate XIX.) as compared with this (dotted line B). This increase of beam will certainly cause an increase to resistance; but, if you make your form that of full line C, you will correct the increase due to the extra beam by a reduction in the fineness—the one corrects the other. Professor Biles asked me to explain line 7 of the first table. There, I may say, the horse-powers are taken directly from the curves, with no corrections made for any excess of initial friction due to excess of power which is provided above what is required for the speed dealt with. In the same way, I do not take into account a great many small things. I do not, in this paper, profess to go in for any of the smaller refinements. All I have attempted to do is to show, in a general kind of way, the effect, and the relative values, of skin friction and wave-making, and I have to thank the gentlemen who, even at short notice, have taken part in the discussion.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I have to move that a very hearty vote of thanks be accorded to Mr. Hamilton for his most interesting paper.

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The following communication has been received from Mr. Archibald Denny on the subject of Mr. James Hamilton's method of estimating skin friction, wave-making, and total indicated horse-power:—

FIGURES FOR VESSELS BUILT BY MESSRS. WILLIAM DENNY & BROTHERS.

	1	2	3	4	5	6
Length	270′	270′	270′	270′	270′	270′
Breadth	35·75′	34·2′	32·25′	53·3′	32·4′	29·65′
Draught moulded...	13·07′	8·65′	9·72′	16·8′	10·9′	7·61′
Displacement	1,840	1,182	1,260	3,330	1,570	764
Co-efficient...	·511	·518	·520	·483	·574	·439
Speed = $v'L$	16·43	16·43	16·43	16·43	16·43	16·43
Wave-making standard	846	612	624	1,562	677	488
Correction for form	39	48	55	72	188	60
Total wave-making indicated horse-power	885	660	679	1,490	865	428
Skin friction	960	745	772	1,262	860	601
Propeller waste	941	716	740	1,405	879	525
Load engine friction	223	169·8	175·5	332·5	208·4	124·4
Total indicated horse-power	3,009	2,291	2,366	4,490	2,812	1,678
Actual indicated horse-power	3,670	2,060	2,284	6,076	2,544	1,145

The above examples show the result of applying Mr. Hamilton's formula to vessels actually built and tried by my firm. The differences are very large, and are not all in one direction. On further examination of the methods adopted I fear Mr. Hamilton's object will not be attained, as the results must be largely ruled by the efficiency of the propeller, which his method assumes as constant.

The following has been received from Mr. James Hamilton:—"Being absent on holiday, I have not received Mr. Archibald Denny's figures in time, and will have to reserve reply, only observing that the efficiency of propeller, or other things, seem to enter too largely into some of the trials to be used fairly for proving or disproving the value of a formula."

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EXPERIMENTS ON THE EFFECT OF DIRECTION OF ROTATION IN TWIN SCREWS.

By R. E. Froude, Esq., F.R.S., Associate Member of Council.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 31, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

§ 1. A few years ago, in the design of certain of H.M. ships, it was deemed desirable, for convenience in arrangement of starting platforms in the engine-rooms, that the twin screws should be made to turn inwards, when going ahead, instead of outwards as usual; in other words, that the starboard screw should be left-handed and the port one right-handed, instead of *vice versâ*. Model experiments were therefore made at Haslar to determine whether this arrangement was likely to be detrimental to efficiency, and the results showed that, in the models of the particular ships in question, the arrangement was favourable to efficiency rather than otherwise, the difference being almost within the limits of error of experiment. Afterwards, whenever proposed designs of new ships were tested in model at Haslar, with propellers, it being at that stage generally not decided which way the screws were to turn, it became the practice to try both directions of turning in nearly all cases; and there has thus been accumulated a considerable body of results of model experiments on the comparative efficiency of the two directions of turning, which may be of interest to this Institution.

§ 2. The results are exhibited in detail in the accompanying diagrams, and it may be said of them generally that, as in the first experiments already referred to, they show the efficiency difference to be almost unimportant, but in favour of inward turning rather than the contrary. A few words are requisite in explanation of these diagrams.

§ 3. The uppermost three diagrams (see Plate XX.) show, for each model dealt with, and in comparison for both directions of turning, the familiar "hull-efficiency" elements, viz., the wake and thrust deduction percentages, and the net hull efficiency (viz., the product of the wake and thrust deduction ratios), expressed in the form of percentage excess over unity, defect from unity being shown as negative. The fourth diagram has to do with "rotative" efficiency, or "screw efficiency proper," and requires more explanation.

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§ 4. Let us suppose that, in an experiment with the screws working behind model, the speed, revolutions per minute, thrust, and turning moment, are V, R, T, and M, respectively. Next, suppose an experiment with the same screws, working, not behind model, but in undisturbed water, or "in open," as it is commonly described, at speed V′, the ratio $\frac{V}{V'}$ being the "wake" ratio as usually expressed. From the mode of determining wake by model experiments, it follows that, if the revolutions per minute be the same as in the experiment behind model, viz., = R, the thrust will also be the same, viz., = T. The turning moment also *would* be the same, viz., = M, *if* the wake disturbance consisted solely of a forward speed, uniform throughout the region of action of the screws; but, in virtue of the other characteristics of the wake disturbance, the turning moment may possibly be slightly different, let us, therefore, term it M′, and call the ratio $\frac{M'}{M} = \rho$, say.

§ 5. Now this ratio ρ, namely, the ratio of the turning moment in open to the turning moment behind model, is also the ratio of the rotative efficiency behind model to that in open, since thrust and revolutions per minute are the same for both.* The ratio ought therefore, in strictness, to be regarded as a third factor of hull efficiency, representing the effect of the wake to modify efficiency by its turbulence or variety of motion, just as the ordinary wake factor represents its effect to increase efficiency by its general motion. This additional factor ρ has generally been treated as unity,† since model experiments showed that it only differed from unity by amounts too small to be satisfactorily measurable for comparisons between individual cases. But in the present investigation it seemed important to take account of it, since the turbulence of

* It is true that the speed behind model exceeds that "in open" in the ratio of V to V′; but the efficiency factor $\frac{V}{V'}$ is already taken account of by the wake factor of the hull efficiency. To avoid any confusion, it may be as well here to set forth the whole efficiency account *in extenso*, using the symbols adopted in the text, with the addition of F′ to represent the resistance of model without screws working behind. [The resistance with screws working, or augmented resistance, is equal to T, the thrust.] We thus get—

$$\text{Net total efficiency} = \frac{F'\,V}{2\pi\,R\,M}$$

$$= \frac{F'}{T} \times \frac{V}{V'} \times \frac{M'}{M} \times \frac{T\,V'}{2\pi\,R\,M'}$$

where the four factors are successively as follow:—(1) Thrust deduction, (2) wake, (3) the factor ρ, (4) the rotative efficiency, or "screw efficiency proper," in undisturbed water. In the actual experimenting, it is, of course, not always possible to hit off the intended speeds V and V′ with perfect precision, but the correct values of T, M, and M′ for these intended speeds may be very precisely inferred from the values obtained at the slightly differing speeds of actual experiment.

† On this point see my 1883 paper, Trans. I.N.A., Vol. XXIV., pp. 239, 240.

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wake must probably involve some twisting or rotary motions, which might well affect efficiency differently for the two directions of turning. And this *à priori* view is borne out by the present experiments, which pretty consistently show a significant difference in respect of this ratio ρ between outward and inward turning, to the advantage of the latter.

§ 6. The fourth diagram, therefore, shows, under the title of "Relative Rotative Efficiency," this additional factor of efficiency, namely the ratio ρ, or $\frac{M'}{M}$, in the form of percentage excess over unity, defect from unity being shown negative. The (positive) difference between the ordinates for the two directions of turning, consequently shows (in percentage) advantage of the one direction of turning over the other, on the score of rotative efficiency; and the algebraic sum of this difference and that between the corresponding ordinates of the third diagram, shows the corresponding net balance of percentage advantage in total efficiency, including the hull efficiency as ordinarily reckoned.

§ 7. The experiments with each model extended over a considerable range of speed. The hull-efficiency elements themselves varied with speed, as they have generally been found to do, in a significant and consistent way. But it did not appear that the relation between the results for the two directions of turning was, in any consistent way, dependent upon speed. Accordingly, in preparing the results which are given in the present paper, the mean results have been taken of all the experiments with each model, irrespective of speed.

§ 8. It will be seen that, of the total list of 21 forms for which the model results are given in the accompanying diagrams, Nos. 1 to 3 are battleships; Nos. 4 to 15, cruisers; No. 16, a vessel of specially shallow draught with Thornycroft pattern of stern; and Nos. 17 to 21, destroyers. No. 16 is singular in showing a hull efficiency materially in excess of unity, but shows nothing exceptional in the relative efficiencies for the two directions of turning. And, in this latter respect, the results in general do not show any clear and consistent difference between the different classes of vessels composing the list. The differences in this respect between the individual vessels, which, in a few cases, are of tangible amount, I am inclined to attribute rather to accidental concurrence of minor errors in the experimenting than to any genuine difference in the conditions.

§ 9. It would seem, therefore, that the safest and most instructive conclusions derivable from these experiments, may be obtained by taking a mean of all the results irrespective of the classes of vessel which the models represent. We thus get :—

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Mean excess of thrust deduction percentage, turning inwards, relatively to turning outwards...	0·19
Mean excess of wake percentage, do., do.	0·65
Mean excess of net hull-efficiency percentage, do., do.	0·37
Mean excess of relative rotative efficiency percentage, do., do. ...	1·12
Consequent net balance of percentage advantage, in respect of total efficiency, of turning inwards relatively to turning outwards	1·49

§ 10. It appears from these figures (and is indeed evident from inspection of the diagrams) that—

(1) Inward turning, as opposed to outward turning, has on the average a slight advantage in respect to net hull efficiency.

(2) This advantage is due entirely to an excess in wake, which is partly counteracted, but not completely neutralised, by a smaller excess in thrust deduction.

(3) In respect of the "relative rotative efficiency," or efficiency factor ρ (*vid. sup.* § 4), inward turning has almost invariably the advantage over outward turning, the efficiency factor being generally greater than unity in the former and less than unity in the latter.

§ 11. The amounts in question are, however, all very small, and the mean net efficiency advantage ascribed to inward turning by these results (as above noted) is only 1·5 per cent. Therefore, taking all the circumstances into account, the results hardly do more than afford us good assurance that twin screws may be made to turn inwards instead of outwards, without sacrificing efficiency.

DISCUSSION.

THE following remarks, communicated by Mr. JOHN DUNCAN (Member), were read by the Secretary:—"I was very much interested on reading Mr. Froude's paper to find that his conclusion is opposed to a result obtained with a small twin-screw vessel built by my firm two years ago. Mr. Froude is careful to state in paragraph 1 of his paper that 'in the models of the particular ships in question, the arrangement (that is, turning the screws inwards) was favourable to efficiency, rather than otherwise,' and in paragraph 11 he says that later experiments with other models showed the same results as the first. In paragraph 2, however, he makes no reference to the 'particular ships in question,' but states as his final conclusion that, 'the results give us good assurance that the twin screws may be made to turn inwards instead of outwards, without sacrificing efficiency.' He thus leaves it to be inferred that, for any vessel, irrespective of form, while it is not safe to count upon an advantage from turning the screws inwards, still, the probability is that there would be a slight gain, and, at any rate, there would be no loss of efficiency. If this conclusion is published as the finding of so eminent an authority as Mr. Froude, without some qualification, it may be seriously

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misleading, and therefore I give below some particulars of the trials of the twin-screw steamer *Kia Ora*, the vessel referred to above. Her dimensions are, 120 ft. length between perpendiculars, by 23 ft. beam, by 12 ft. 3 in. depth moulded. She is fitted with two sets of triple-expansion engines, which are built with locomotive guides, so that they may be turned either way to go ahead according to the screws fitted on the shafts. At her trials the draughts were 5 ft. 7 in. forward, and 6 ft. 1 in. aft, to bottom of keel, which is 5 in. deep, and the displacement was 280 tons. At this condition of trim and displacement a speed of 10 knots was guaranteed. The trials were between the Clock and Cumbrae Lights on the Clyde. The first trial was on Saturday, June 6, 1896, and the mean speed of four runs, with the screws running inwards, was 9·11 knots. The vessel was brought back to the yard, and the propellers shifted to opposite shafts—no other alteration whatever was made on the machinery. On Monday, the 8th, the vessel (at the same trim) was again run four times on the Lights, the screws on this occasion turning outwards, and attained a mean speed of 10·34 knots, or 1·23 knots more than on the Saturday, a considerable gain in favour of turning the screws outwards. There was plenty of steam on both occasions, and the engines were fully opened out. The mean revolutions were practically the same on both trials. The weather conditions were good on both days." (For further information from Mr. Duncan, see page 68.—Ed.)

Mr. Macfarlane Gray (Member of Council): I think that Mr. Duncan ought to be asked to send diagrams of these engines, because the valve motion might be different in going ahead and going astern. An engine does not give the same diagram when the cranks are going in the reverse order; therefore he might repeat the experiments and produce the diagrams for these remarkable results.

Mr. Alfred Watkins (Member): After reading the title of this paper, I thought I was going to hear an explanation of the wonderful difference that exists between the performance of vessels—with the propellers running inwards or outwards—instead of hearing that they give the same result. My experience with twin screws is not very great, but I have found the speed better with the propellers running outwards; and, in respect to handiness or manœuvring power, I have found the outward running far superior. I made experiments with one vessel, the propellers, as originally fitted, running inwards. I was under the impression, at the time of building the vessel, that it would make no difference either in speed or handiness, but thought it more convenient to run the engines inwards. This vessel, the screw tug *Oceana*, 140 ft. long, with 13 ft. draught aft and 8 ft. forward, was found to be, when tried, less handy than a single screw tug, the latter using, when manœuvring, both the helm and engines. With the helm amidships, and the engines working against each other, the *Oceana* would not turn in the Thames at Blackwall, as she moved slowly ahead and turned also very slowly, making a circle about half a mile in diameter. The propellers were shifted (no other alteration being made), and then with engines working against each other, and the helm amidships, as before, the vessel turned in a circle, as near as I could judge, rather less than twice her length. She appeared to turn on her bow, and thrash a circle, at that radius, with the propellers, the circle of foam being very distinct. I think that the explanation is that there are two actions connected with the turning of a twin-screw vessel by her propellers alone. The paddling action caused the water thrown off from the propellers, and the thrust of the propeller shaft. Everyone knows that when the engines of a single-screw steamer are put astern, the vessel's head cuts in a certain direction, and the vessel can be much more easily, partly, or entirely turned round in that direction by the use of the helm and propeller than in the other direction. The screw being right or left handed settling which is the easy way. With a twin-screw steamer, with the ahead-going propeller running outwards, this

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paddling or cutting action *assists* turning. When the ahead-going propeller runs inwards, this action *retards* turning. I think that, if an experiment were made with flat fore and aft blades on the two propeller shafts, the vessel would be found to turn with considerable rapidity when the two shafts revolve in the same direction, as they do in a twin screw when one engine is reversed, and that this turning would be in such a direction as to assist turning a vessel fitted with outward-running propellers. I am not prepared to comment on the question of fact stated in the paper. I would only say, it seems extraordinary that the fact should be so entirely different to my small experience.

Mr. Froude: I do not say anything about the steering or turning. It is simply a question of speed.

Mr. Watkins: I thought the great idea in twin screws was that they should be handy.

Sir William White, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): May I interpose at this moment to say that the question of steering which has been introduced has nothing to do with the subject of this paper. While I do not challenge the accuracy of the statement made by the last speaker respecting difficulties in steering certain twin-screw ships, I may say that a somewhat large experience proves that the turning *inwards* of the screws involves no necessary difficulty in the steerage. These ships are as workable as others with the screws turning *outwards*. It is not a difficult matter to explain why some twin-screw ships do not steer well, nor should it be assumed that bad steerage is necessarily due to the direction in which the screws are turned. There are many other features in the design of ships which affect their steerage. It would be going away from the purpose of this paper to discuss that now. If, at some other time, the last speaker will give us a little more detail of the particulars of the form of the stern of this vessel, the area of the rudder, the position of the rudder, and so on, and will state how the screws were placed in relation to the rudder, then we can discuss the steerage intelligently. The real purpose of this paper is to afford an answer to the question: When certain advantages can be obtained in the design and working of the machinery by turning the screws inward, instead of outward, in a twin-screw ship, is that arrangement likely to prejudice efficiency of propulsion? Mr. Froude has shown by a great many model experiments that there is no reason to anticipate such loss of efficiency by turning the screws inward. We have put that matter to the test; we do not depend upon model experiments. We have had the courage to proceed from model experiments to actual ships, and can now refer to many high-speed trials where the efficiency has been excellent with the screws turned inward. In these particular ships no difficulty of steering has occurred. Of course one knows that very extreme and contradictory opinions have been previously expressed on this subject. My attention was first called to it twenty years ago by the late Mr. Samuda. He had an experience where difficulty occurred, partly in steering, and partly in obtaining the estimated speed. The difficulty disappeared when the direction of turning of the screws was altered. In the Royal Navy the general practice has been to turn the screws outward. There are, however, certain advantages in the engine-room arrangements when the screws turn inward. It is now established that if anybody wants to realise those advantages in ships well formed at the stern, and with appropriate rudder arrangements, he may do so without suffering in efficiency of propulsion or steering. That is my conviction. In relation to the letter from Mr. Duncan, if those speed observations were correct, then between the speed of about 9 knots and that of $10\frac{1}{3}$ knots there must have been a difference of practically from 30 to 35 per cent. in the power. I am sorry Mr. Duncan is not here to give us more information, and I would suggest that we ask him to give us particulars of the form of the stern of the vessel, because I cannot help thinking that the difference in result must have been due to other causes than the change in direction of the turning of the screws.

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Mr. J. I. Thornycroft, F.R.S. (Vice-President): Gentlemen, Mr. Froude has made some allusion to a boat with the Thornycroft system of stern. I do not know whether that refers to a vessel built by my firm or not, but, looking at the diagram, it is very instructive, because, in this particular form of stern, where the water is very much enclosed, as it were, by the form of the vessel aft, the water set in motion by the vessel tends to collect so as to give to the propeller or propellers a very considerable quantity of water which has been accelerated by the ship. The effect of this is favourable to propulsion and to good results in some ways comparable with the battleship No. 1 in the table. If you look at the table you will find in No. 1 in the diagram is given the wake per cent. It is very large—something over 17 per cent.—and is very much the same as in the vessel with tunnelled stern. I think it is probable this first vessel, the battleship, has full lines, and the screw is well up under the stern, and in the shallow vessel it is not so, but is enclosed within the ship. With regard to what has been said about Mr. Duncan's experiments, in which the screws were changed from one shaft to the other, the engines being then run, of course, in the best way, I think, as Mr. Macfarlane Gray has pointed out, that it is highly probable the link motion largely affected the power. I think it would be very interesting to get to the bottom of this, and diagrams indicating it would be most valuable, but it is highly probable that the engines developed different power on the two trials.

Mr. S. W. Barnaby (Member of Council): I should simply like to ask Mr. Froude if he would tell us if he has also tried screws slightly overlapping, and running in the same direction, because Monsieur Normand, I know, believes that improved efficiency is obtained by running them in that way.

Mr. R. E. Froude, F.R.S. (Associate Member of Council): With reference to Mr. Barnaby's question, we did try experiments with twin screws turning in the same direction. I think they were almost in contact, but not overlapping. At this moment I forget what the result was, but I think there was nothing very successful about it. I do not think it gave quite so favourable a result as turning inwards. That was only one particular case, of course. As to the general conclusions to be drawn from these experiments; in the first place, we only include altogether twenty-one forms. We certainly have not exhausted all the possible category of forms; because these twenty-one are all forms for ships for the Navy, and they differ in characteristic ways from nearly all kinds of merchant ships, so that the result cannot be said to be in any way exhaustive. It is quite possible, if you were to try the forms of ordinary merchant ships, you might find a consistently opposite result would be obtained. Then again it must be recollected that, after all, these are model experiments, and in the working of propellers there are many conditions which are distinctly and significantly different in the model from what they are in the ship. The dimensions of the wake are much greater, relatively, in the model, owing to the proportionately greater effect of skin friction. In the working of the small-scale propellers the turbulences, and phenomena of that kind which affect the result, would not reproduce accurately what occurs in full size. Therefore we must not run away with the impression, in consequence of these results, that everything is decided; and if cases were to arise of actual ships in which it was distinctly proved that there was a loss of efficiency by turning inwards instead of outwards, it would not surprise me. As to the particular point raised by Mr. Duncan's letter, I think Mr. Thornycroft and Mr. Macfarlane Gray have said enough. The fact that the same engines were used, turning in the opposite direction (and, as far as I understand, no indicator diagrams were taken), is sufficient to rob the result of any conclusiveness, and the difference again is so large that, as Sir William White pointed out, it proves a great deal too much.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I think we must accord a hearty vote of thanks to Mr. Froude for his admirable paper.

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In response to the demand for further information, Mr. John Duncan has written the following letter :—

June 26, 1898.

DEAR SIR,

I have to acknowledge the receipt of your letter of the 17th, and also the copy of the discussion on Mr. Froude's paper.

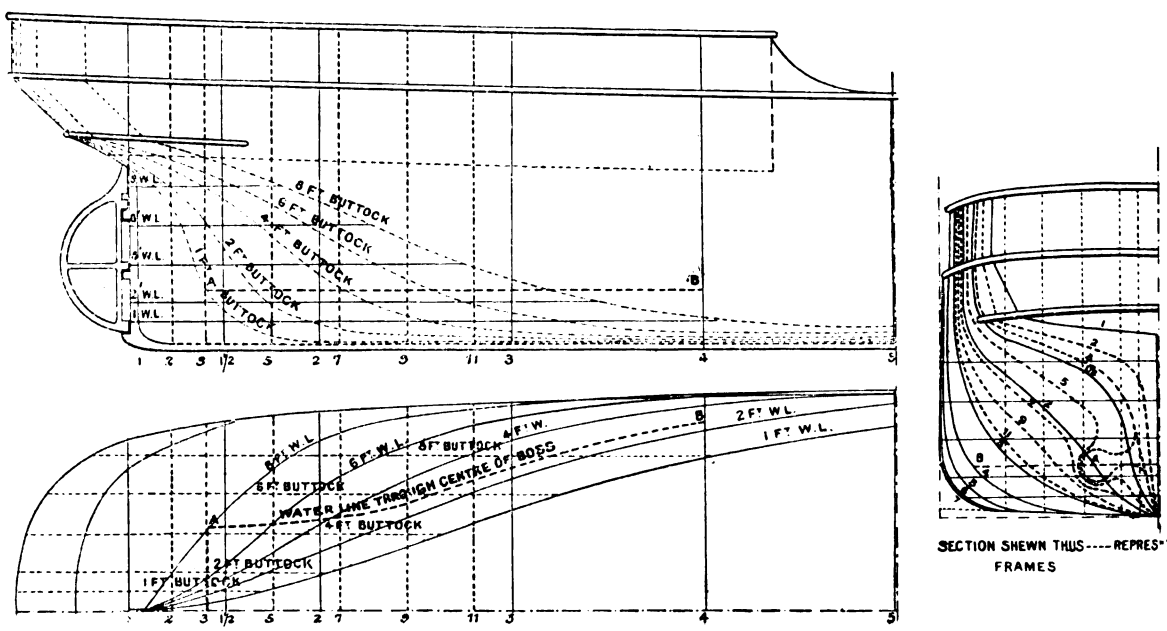
I regret exceedingly that Messrs. Muir & Houston, who engined the *Kia Ora*, inform me that the diagrams taken at the first trial cannot be found.

There was a difference of opinion when the engines were being designed, between the owners, and Messrs. Muir & Houston and ourselves, as to the way the propellers should be run, and while deferring to the owners so far as to agree that they should run inwards in the first place, we arranged that the engines should be run either out or in with equal efficiency. The valves have the same cut off for each way of turning, and the guides of the piston rods are of the locomotive type, so that the bearing surfaces are the same running either way; and as, moreover, the full value was taken out of the boiler on each trial, it follows that there could be little or no difference in the horse-power with the engines running out, or in, at the same number of revolutions.

Yours very truly,

JOHN DUNCAN.

GEORGE HOLMES, Esq.



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TRUNK-DECK STEAMER *OSCAR II.*

By W. Hök, Esq., Member.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 31, 1898; Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President, in the Chair.]

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§ 1. A TRUNK-DECK STEAMER is a vessel having erected on the midship portion of the upper deck two fore and aft vertical girders, which extend for at least one-half of the vessel's length (Figs. 1 and 2, Plate XXI., and Fig. 4, Plate XXII.), are efficiently incorporated with the main structure of the vessel, and carry on the deck connecting their upper members all hatches, deck machinery, loading and discharging gear, pipes, ventilators, companions, &c. (Fig. 4).

§ 2. Everybody who has experience in designing and building vessels carrying large cargoes on a relatively light draught knows that a vessel classed in Lloyd's, and whose length exceeds thirteen times the depth, must have a bridge extending for at least one-half of the vessel's length erected on the weather deck, in order to provide the structure with adequate strength. This way of acquiring strength is not only costly, but has the drawback of adding to deadweight carriers unserviceable enclosed spaces, which increase the tonnage on which the dues are paid. To overcome this difficulty (*i.e.*, the requirement of fitting a compulsory midship erection), the breadth of vessel is sometimes increased, and the length correspondingly decreased, so as to bring the number of depths in length below thirteen; at other times the depth is increased, keeping length and breadth constant. But the former expedient has its limits, which are soon reached, and, further, leads to building vessels of abnormal proportions of length to breadth and depth to breadth, in fact, to vessels of inferior sea-going qualities; and the latter to expensive ships of excessive tonnage.

§ 3. There is a way, however, of reducing the abnormal tonnage in vessels of such extreme proportions as to necessitate the fitting of a bridge erection extending over, at least, one-half of the vessel's length without either increasing cost or reducing strength, and this consists in shifting the sides of the midship erection inward, and parallel with the centre line (Fig. 1), until that measurement capacity, and consequently also tonnage, is obtained (within reasonable limits, of course) which the trade in which the vessel is engaged renders necessary.

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But in order not to inflict any loss of strength by this operation, the following precautions must be taken:—First, the shifted bridge sides (or the trunk sides) must be well stiffened, so as to prevent any deformation in a lateral direction; secondly, they must be most efficiently supported, so as to maintain their position with reference to the floors; and, thirdly, they must be well incorporated with the upper deck, so as to operate conjointly with the sides and bottom in resisting any strains to which the vessel is subjected.

§ 4. The preceding paragraph states the principles which form the basis for the construction of trunk-deck vessels, and describes the defect in ordinary vessels which led up to the designing of a novel type, viz., a disproportionately large tonnage, in relation to deadweight, in vessels of such extreme proportions as to require to have fitted on the upper deck, for purposes of strength, a midship erection extending over one-half of the vessel's length.

§ 5. It has been stated that, for the mere sake of strength, a trunk extending one-half the length of vessel is sufficient; but, in order to obtain uniformity of general arrangement throughout, the trunk is carried to the after end of forecastle and the fore end of poop (Figs. 2 and 4). It is not connected to these erections, however, but a passage-way is left at each end to enable the crew to pass from one side of the main deck to the other without ascending to the trunk deck. To keep the erections separated admits, further, of good accommodation in forecastle and poop; and the short wells that are thus formed prevent seas that find their way over the forecastle, or the poop, from travelling the whole length of the navigating platform, and imperilling the safety of hatch openings, deck machinery, deck pipes, officers, and crew. The seas descend from the forecastle or poop direct to the main deck, and return through the clearing ports at side into the sea without reaching the trunk deck at all.

§ 6. By this uniform arrangement every cargo hold in the vessel is provided with a trunk which, besides, forms a navigating platform throughout the whole length of vessel, beyond the reach of any seas, and a place of safety for all vulnerable parts on the deck, including all openings, such as hatches, ventilators, companions, &c., and all deck machinery and accessories, as winches, derricks, all deck steam-pipes, steering rods, &c. Of course, short, narrow gangways are fitted between trunk and forecastle, and trunk and poop, so as to enable the crew to pass the whole length of vessel without descending on the main deck (Fig. 4).

§ 7. It will be noticed (Fig. 4) that the sheer of the top of trunk differs from that of the main sheer, and is practically straight. This reduces the capacity in the end holds, resulting in less strains in the loaded vessel, and increases the capacity in trunk aft relatively to trunk forward, which relative increase, although small, suffices to make these vessels trim by the stern, like the old raised quarter-deck vessels, even when loaded with homogeneous cargo.

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§ 8. The trunk-deck construction is eminently adapted for reducing pillars in cargo holds to a minimum (Fig. 2). It is incontrovertible that a deck combined with two vertical webs rigidly supported, and running right fore and aft the whole length of vessel (Fig. 1), is much stronger than an ordinary flat deck supported by pillars in the usual way. The webs in this construction—*i.e.*, the trunk sides—receive most efficient support from all the bulkheads (Figs. 2 and 4), and from pillars placed in the holds. The spacing of these pillars depends upon many considerations; but, in a combination consisting of an efficient design of pillar, a depth of trunk of 6 ft. to 7 ft., and a reasonable length of hold, only one pillar is required at each side of trunk in each individual hold—*i.e.*, eight pillars in a vessel of four holds.

The vessel to which I am presently going to refer is fitted with more pillars than strictly necessary, but this was done for a certain purpose; however, taking the vessel as built, her pillars are less than one-fourth the number required for an ordinary vessel of equal size (Fig. 2).

The pillars in vessels of this type perform a double duty. In ordinary vessels pillars are merely struts for supporting the deck from the floors or double bottom. They are of little value as struts in supporting the floors against external pressures—for a flat deck has little resisting power—nor are they of any moment as ties, due to their being inefficiently attached to beams and floors; but, in trunk-deck vessels, the pillars not only act as struts in supporting decks and trunk, but as struts in supporting floors against external pressures, such as are produced in docking, grounding, or when the vessel is afloat, and as ties in supporting floors (Figs. 1, 2, 3, and 4) against excessive internal pressures of a local character, such as are produced, for instance, through imprudent loading, for the trunk girders are capable of resisting vertical forces of considerable magnitude without fear of unsafe deflection. In fact, when the pillaring is carried out in a certain way, trunk-deck vessels may be considered to have, comparing a ship to a girder, four vertical members instead of two, as in ordinary vessels, the additional girders being, so to speak, the trunk sides carried down to the top of tank, enabling these vessels to resist racking and certain twisting strains in a twofold degree.

§ 9. The main-deck plating inside the trunk may be retained, and the trunk spaces formed, practically speaking, into narrow 'tween decks; but the main-deck plating, or plating and beams inside trunk, may also be suppressed. The trunk forms, then, in conjunction with the holds below, one large cargo space (Fig. 1). It is evident that such a construction provides, without further modification, an excellent natural feeder to each hold for such cargoes as grain, coal, oil, &c. And as cargoes cannot possibly shift, when placed in holds provided with efficient feeders, shifting boards, as required by the Board of Trade in ordinary vessels, are in this type entirely superfluous. This fact is well understood by naval architects, and we can only hope the time will

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eventually come when steamers provided with natural feeders, such as turret and trunk-deck steamers, will be exempted by the Board of Trade from shifting boards in holds.

In order to increase the efficiency of the self-feeding and self-trimming arrangements, the round of beam of the main deck is made double that of ordinary vessels (Fig. 1). It was thought, however, that the main deck would be difficult to walk on, but experience shows the contrary, and, further, water coming in over the sides is returned into the sea in doubly quick time.

§ 10. The step in the deck in a transverse direction, if I may so term the trunk, constitutes, at the same time that it forms a feeder and a navigating platform, an obstacle against any lateral shifting of deck cargoes. As a further improvement, bulwarks are fitted to these vessels (Fig. 4), and between them and the trunk deck cargoes are absolutely secure. These bulwarks form also some protection against the seas. They keep small seas out; and the big seas entering over the rail rapidly pass out again through the large openings provided at intervals for this purpose.

Consider here, for a moment, the action of a sea coming over the side. It will sweep obliquely the deck of an ordinary vessel, carrying with it everything that is not sufficiently secured. In a trunk-deck steamer the sea coming over the side strikes the trunk at an angle, diverges along the unobstructive main deck, strikes the slanting bridge front and disappears through the bulwark openings into the sea without ever reaching the trunk deck and the vulnerable parts (Fig. 4). Captain Nordahl of the *Oscar II.* reports that, although he had exceptionally bad weather in the Bay of Biscay, the seas repeatedly washing over the main deck, not a single sea passed on to the trunk deck; and, I understand, the experience in turret-deck vessels is similar.

§ 11. This type having a square gunwale, no difficulty presents itself in extending the navigating platform to the sides of the vessel at any part of her length. Side houses can easily be fitted amidships (Figs. 1 and 4), which, in conjunction with the trunk, form a bridge from which the boats are lowered, and on which the accommodation for captain and officers is placed (Fig. 4).

§ 12. The hatches being on a higher level than the deck at side, it is sometimes found necessary to erect temporary platforms consisting of deals extending from trunk deck to a horizontal spar lashed to two uprights supported by the bulwarks (Fig. 4), so as to make the process of loading and discharging similar to that of ordinary vessels. The captain of the *Oscar II.* reports that in consequence of such a simple arrangement answering the purpose, he does not consider the erection of platforms a serious inconvenience. It may be interesting to note, in connection with this matter, that the vessel shown in Fig. 4, and to which I am presently going to refer, discharges a cargo of iron ore with her own gear at the rate of 130 tons per hour.

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§ 13. In constructive detail a trunk-deck steamer differs only in a small degree from an ordinary vessel, and what difference there is, is almost entirely necessitated by the dissimilarity in form between the upper deck structure of this type and that of the ordinary type. The bottom and sides are identical with those of an ordinary vessel, but the decks and pillaring are different. The trunk frames are bracketed to the main deck beams, and the trunk-deck beams are either kneed or bracketed to the trunk side frames (Fig. 1). The whole framework is plated over with heavy plating, having double-riveted landing edges up to and including the trunk-deck stringer plate (Fig. 1). Strong beams are fitted at intervals in way of main deck (marked *b* in Fig. 2). These beams are carried straight across, tying the vessel's sides together, and without the assistance of a single inch of cross plating in way of main deck inside the trunk. The trunk deck is, of course, plated over from end to end; but the whole space below this deck forms an open cargo space, with no other obstructions than the few cross beams in way of main deck (marked *b* in Fig. 2), and the few substantial pillars in line of trunk side from main deck to tank top, marked *a* in Fig. 2, there being no hold beams whatever (Fig. 2). The pillars in question consist of channel bars and two bulb angles riveted together (Fig. 3). Their upper ends are efficiently connected and bracketed to trunk side and strong beams, and their lower ends to the tank top (Fig. 3), so as to form, as stated in paragraph 9, both ties and struts. Webs are fitted inside trunk in way of strong beams and pillars; and alternately with these webs brackets are fitted outside trunk on the main deck, as shown in Fig. 1, to prevent any possible deformation of side from existing twisting forces. The bridge structure, except framing, is fitted up after the completion of the trunk, the bridge beams extending from side of vessel to side of trunk, and bracketed against it (Fig. 1). The bridge front likewise abuts against the trunk side.

Flanging was resorted to in the *Oscar II.* where practicable, and it may be of interest to note that she was probably the first vessel not built by Messrs. Doxford in which joggled plating was extensively adopted (Fig. 1).

§ 14. In order to show further differences between this type and ordinary vessels, I will give particulars of the *Oscar II.*, built by Sir James Laing in 1896 to the order of Axel Johnson, Esq., of Stockholm.

The owner's principal requirements were as follow:—

Class	Bureau Veritas.
Carrying capacity	5,400 tons.
Permanent bunkers	400 tons.
Load draught not exceeding	20 ft. 1 in.
Measurement capacity of holds not less than	260,000 cubic ft.
Density of cargo	52 cubic ft. to a ton.
Water ballast not less than	1,000 tons.
Speed on loaded trial	10 knots.

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A favourable opportunity here presented itself for ascertaining the capabilities of the trunk-deck type as a carrier of large cargoes on a light draught. The vessel, however, being intended for measurement cargo as well, it was not possible to show in this particular case the smallest possible tonnage per ton of deadweight, which, in a first vessel of a novel type, was, of course, much to be regretted.

The dimensions finally decided on were :—

Length between perpendiculars	348 ft.
Moulded breadth	48 ft.
Moulded depth to main deck	23 ft. 9 in.
Depth to bridge deck at side	31 ft. 6½ in.
Depth to bridge and trunk deck at centre	32 ft. 5½ in.
Depth to trunk at side	32 ft.
Freeboard to top of trunk at side	12 ft.
Width of trunk	22 ft.
Round of beam on main deck	23 in.
Round of beam on bridge and trunk deck	11 in.
Main sheer of vessel, forward	7 ft. 6 in.
Main sheer of vessel, aft	3 ft. 6 in.
Top of trunk, straight with a slight rise at ends	
Indicated horse-power on trial	1,550.

The specification contained the following principal items, over and above the requirements of ordinary cargo steamers :—

Depth of cellular bottom, 4 ft., or 10 in. in excess of rule :
Ice bow ;
All decks, tank top, material in bunkers, including frames, web frames, stringers, angles, &c., 20 per cent. above rule requirements ; an especially good and complete outfit, extra large donkey boiler, 16 Samson posts and 16 derricks, nine winches, &c. (Fig. 4) ; the collective weights of these items, over and above an ordinary specification, representing 70 tons.

§ 15. The vessel when finished came out as follows :—

Deadweight	5,500 tons.
Load draught	20 ft. 1 in.
Measurement capacity in holds, measured to underside of beam and inside of cargo battens (cargo battens fitted in trunk also)	262,670 cub. ft.
Water ballast	1,004 tons.
Bunker capacity	425 tons, including bridge.
Speed	10·13 knots on loaded trial.
Gross tonnage	3,551 tons.
Net tonnage	2,286 tons.
$\frac{\text{Deadweight}}{\text{Net tonnage}}$	$= \frac{5,500}{2,286} = 2{\cdot}41$
$\frac{\text{Measurement capacity of holds}}{\text{Net tonnage}}$	$= \frac{262,670}{2,286} = 115.$

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§ 16. If this vessel had not been built in excess of ordinary requirements, she would have carried 5,570 tons (§§ 14 and 15). Further, as I have reasonable hopes of reducing, by a slight alteration of structure, the net tonnage to about 2,200 tons or under, in future vessels of a similar size, a possible value of $\frac{\text{deadweight}}{\text{net tonnage}}$ for a plain cargo vessel of this type carrying 5,570 tons on 20 ft. 1 in. is $\frac{5,570}{2,200} = 2{\cdot}53$, or slightly more.

§ 17. Finally, I will complete this comparison by appending the estimated dimensions, tonnage, and additional cost of an ordinary steamer classed in Lloyd's or Veritas built to carry 5,570 tons on 20 ft. 1 in., and to steam 10·13 knots on loaded trial.

Length between perpendiculars	355 ft.
Moulded breadth	49 ft.
Moulded depth	23 ft. 5 in.
Forecastle	33 ft.
Bridge, extending over at least one-half of the vessel's length	180 ft.
Poop, short and open.	
Sheer, as per trunk-deck steamer.	
Gross tonnage with accommodation on bridge	... 3,880 tons.
,, ,, ,, ,, in ,,	... 3,806 tons.
Net ,, ,, ,, on ,,	... 2,511 tons.
,, ,, ,, ,, in ,,	... 2,460 tons.

Cost over trunk-deck steamer, 8 to 10 per cent.

Or, if the vessel is increased in depth so as to make $\frac{\text{length}}{\text{depth}}$ less than 13 :—

Length between perpendiculars	355 ft.
Moulded breadth	49 ft.
Moulded depth	26 ft. 3 in.
Forecastle	33 ft.
Bridge	75 ft.
Poop, short and open.	
Sheer, Lloyd's normal, say, forward, 5 ft.; aft, 2 ft. 6 in.	
Gross tonnage	3,792 tons.
Net	2,450 tons.

Cost over trunk-deck steamer, 8 to 10 per cent.

§ 18. It appears, then, that a raised central deck imparts to vessels certain good qualities, which I venture to summarise as follows :—

(1) Capability of providing, within reasonable limits, the exact measurement capacity required for most cargoes, especially so in vessels of extreme proportions (Fig. 1).

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(2) Great general safety, by providing :—

(*a*) A safe navigating platform in the central part throughout the entire length of vessel ; *i.e.*, an efficient protection for officers and crew (Fig. 4).

(*b*) Efficient protection of hatch openings, ventilators, companions, deck machinery, deck pipes, cargo gear, steering rods, &c. (Fig. 4) ;

(*c*) Immunity from danger in carrying deck cargoes (Fig. 4).

(*d*) Prevention of large volumes of water accumulating on deck, thereby increasing the vessel's rising power, and the safety of decks generally (Fig. 4).

(3) Trim by the stern, even when loaded with homogeneous cargo throughout (Fig. 4).

(4) Cargo holds almost free from obstructions (Fig. 2).

(5) Efficient protection to bottom of vessel against excessive downward pressures, as in the case of careless loading ; and against excessive upward pressures, as in the case of docking, beaching, or grounding (Figs. 1 and 2).

(6) Being provided with natural feeders to all holds which renders the shifting of cargoes impossible (Fig. 1).

(7) Hence the absolute superfluity of shifting boards, as required by the Board of Trade for ordinary vessels (Fig. 1).

(8) Greater rigidity over ordinary vessels not requiring a bridge erection extending over one-half the vessel's length, through having a larger mass of material disposed vertically (Fig. 1).

(9) More reserve buoyancy than ordinary vessels of equal dimensions when these are not of extreme proportions (Fig. 1).

(10) Small register tonnage per ton of deadweight capacity.

(11) Small register tonnage per ton of measurement capacity.

(12) For given deadweight on given draught and speed, a trunk-deck vessel can be made of smaller size, tonnage, and for less cost, this being especially the case in vessels carrying large cargoes on a relatively light draught.

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APPENDIX A.

§ 19. Sketches of a vessel of the type here described were made in March, 1895.

The order for the *Oscar II.* was placed with Sir James Laing on February 26, 1896. After several delays, due to various causes, the vessel was launched on October 24, and sailed for Genoa on December 23, 1896, after a successful loaded trial.

APPENDIX B.

The Comparative Seaworthiness of Vessels with Central Erections.

§ 20. Before fixing the value of a central erection it must be ascertained if a sea so huge as to break over the side of an ordinary bridge erection would break over an erection of equal height if placed in a central position.

It is probable that the height of such a wave would gradually decrease, and its force be partly spent as it traversed the deck towards the central erection. If that be so, a wave of this description would advance no farther than to the trunk side, and never reach the top of trunk deck or navigating platform. It must necessarily be left in the hands of those navigating vessels of this type to ascertain the truth of this hypothesis, but the persistency with which captains of turret vessels maintain that green seas are absolutely unknown on the turret deck seems to lend some colour to the theory here advanced.

§ 21. The value of a central erection is composed of two parts, buoyancy value and protective value.

By the latter I mean the value of a central erection as a protection to all vulnerable parts, as hatches, companions, ventilators, deck machinery, pipes, cargo gear, steering rods, &c. It is probable that the narrower the trunk is in proportion to the breadth of vessel, the higher is its protective value and the lower its buoyancy value (Fig. 1); and the wider the trunk is the lower is its protective value and the higher its buoyancy value. Therefore, the true value of a central erection is difficult to estimate, but it can only be correctly gauged by splitting it up into the two separate and antagonistic parts, buoyancy value and protective value.

DISCUSSION.

Mr. B. Martell (Vice-President): I do not think, Sir William, that I have much to say on this subject, but still I shall be very happy to make a few remarks. Of course the proof of the pudding is in the eating. That is an old adage, but there is a good deal of truth in it. I may say that, since this description of vessel first came under our notice, a great number of them have been built—I do not know whether they are particularly confined to Messrs. Ropner & Sons, but I know a great many have been built by them—and I understand that they have answered their purpose remarkably well. They are very good sea boats, I understand; but whether, as Mr. Hök says, they are capable of defrauding the spirit of the Board of Trade requirements for tonnage I cannot say. It seems to me that is a great point, which we shall hear more of from another paper after this. Whether they carry

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so much more deadweight in comparison to their registered tonnage I do not know, but I do know that a great number of them have been built and are doing their work successfully; in fact, I may say that, in December, 1894, Messrs. Ropner & Sons submitted a plan of this description of vessel to us, and we had consultations and went into the various requirements. I do not believe in what Mr. Hök says as to almost dispensing with pillars altogether, because that is a very serious consideration. If we have a ship regarded as a girder, and it must be considered as that from one point of view, we must have the upper flange of the girder connected with the lower flange, and effectually, so as to bring into effective power both the upper and the lower flange of the girder. Pillars are also as essential in supporting the lower part of a vessel as in supporting the beams. I am so pleased that my distinguished friend, Dr. Inglis, is by my side here, because I can say that that requirement is paid particular attention to on the Clyde above all rivers. I think one reason of it is that they build so very many large passenger steamers there, where they have an immense saloon amidships, and they know that everything must give place to grandeur and space and artistic requirements. That has to be considered in order to carry things out for the comfort of the passengers and to gain their admiration. I have seen some instances where very few pillars have been fitted, and the consequence has been that very serious working has taken place. But I am very pleased to say that, in recent ships which I have seen built on the Clyde, there are very special means taken for connecting the upper flange of the girder to the lower; and then, with all their enlightenment and scientific and practical knowledge they have great artistic sense; and if they have not got it themselves they employ artists to supply it, so that it is astonishing how the pillars, instead of detracting at all from the appearance of a large magnificent space like a saloon, can really be made artistic and beautiful. I only want to show the great attention that is paid by our largest shipbuilders in supplying a sufficient number of pillars to connect the upper portion of the deck with the bottom. I remember when Messrs. Ropner had a long conversation about this ship in 1894, when it was submitted in this way, and we know that shipbuilders are pressed very much indeed by shipowners to do things that their practical judgment does not approve of. A shipowner wants, as a rule, if he can, to carry about 21 cwt. to the ton in his ship. It is very difficult to get that, or to make 37 inches to the yard, but I know they often try to do that, and there is a certain trade coming in now where it is very much more profitable to have no pillars whatever. They want to do away with the pillars altogether, very frequently, but that we cannot agree to. I do not know about having the number of pillars reduced to the number which Mr. Hök says. I do not think a vessel would pass us without having something, or, at least, having the question seriously considered. There is no doubt the trunk-deck vessel is a very good vessel. As I said before, evidence has shown that they are doing their work well, and if owners find that they suit their particular class of trade, and they find that the cost of working them is less, on account of their being enabled to carry—through want of proper supervision by the Board of Trade in measuring them—more in proportion, and that they have less tonnage and carry more deadweight than the ordinary ships, I see no objection to their doing it. Every man must look out for himself in matters of that kind. I do not know that I have a very great deal more to say about the type. There is no doubt as to what Mr. Hök says, that the trunk carried along continuously in this way is like an enormous girder fitted on the top of the ship, and is a great longitudinal support, and that enables some portion of the side plating and the structures and that sort of thing to be reduced, in consequence of the great additional longitudinal strength given by the girder extending fore and aft, and if that is well and efficiently pillared, carrying it down to the floors as is shown there, it would be quite effectual. When you get a ship 280 ft. or 300 ft. long, if you want to support that with about eight pillars, I should be very sorry to say, from my point of view, that that is properly supporting

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it. That requires to be looked into, to see how it can be properly arranged; but, if that continuous trunk of that size is extended down in the way shown and connected properly to the bottom, I think any naval architect would say that the principle of construction, as regards strength, cannot be objected to. I have nothing more to say than that I suppose, if she turns out to be a profitable ship, and shows herself to be seaworthy, and commends herself to the shipowner and the merchant and the underwriter—and she will if no more claims are brought on her than upon an ordinary type of ship—she will continue to prosper and come to the front.

Mr. Robert Ropner, Jun. (Member): My Lord and Gentlemen, as Mr. Martell has correctly said, my firm has built a number of "trunk" vessels. We have been engaged in the design and construction of nineteen such vessels since 1894. I have here a few plans of similar ships to those that Mr. Hök is describing in his paper. The principle involved in the construction of these ships is the erection on the weather deck which lies immediately over the cargo hold of the vessel, of a continuous fore and aft "trunk." It might also be described as the bending up and over of the weather deck. In this type of vessel we prefer to build them with the usual erections, such as bridge, poop, and forecastle, and to scarph the trunk into these erections as at A in the forecastle, and carry it through the bridge and scarph into the poop, as at B (Fig. 2, Plate XXIII.). I think that this method takes full advantage of the girder principle, and of course produces a structure which is a very strong one indeed. Although Mr. Hök does not perhaps state it very clearly, I presume, when he says that when a vessel exceeds a certain proportion, she must have a bridge extending for not less than half of the vessel's length, he alludes to the stipulation in Lloyd's Rules that such vessels are to have a substantial erection extending over the midships, half the length of the vessel. This can be done by means of a bridge, or by extending the awning-deck and raised quarter-deck in part awning-deck vessels. But these methods are open to objections when the owner's requirements are in the direction of a single-decked vessel. The usual method for compensating for excessive proportions, and adding strength to the vessels, is by means of doubling the sheer strake, and fitting closer spaced webs and stringers, and so forth. This material, while, of course, it adds its strength to the vessel, very much detracts from the deadweight carrying of the vessel. The addition of this extra material can be advantageously used in the construction of a trunk on the vessel. All the material which is required for compensation is, naturally, better disposed of in constructing a trunk deck. This plan has the advantage of affording extra cubical space and adding to the reserve of buoyancy of the ship. The ship is also so much deeper in construction, whilst she certainly has a great deal more reserve of buoyancy by the efficient use of this material; her freeboard is therefore favourably affected. Mr. Hök prefers to stop the trunk ends short of the erections. He gives, as one reason, that it provides a means of exit for the seas coming over the forecastle. Now, while I may say that, as a matter of fact, my firm have certainly provided, in the case of vessels having this continuous trunk connected at the forecastle, a breakwater on the forecastle; yet we found by experience this breakwater is not at all necessary, and that the seas do not come over the forecastle, as Mr. Hök thought they would, and sweep along the trunk. We think, therefore, there is no reason at all for stopping the trunk end short of these erections, unless it is for the other purpose he names, viz., providing facilities for traffic from one side of the weather deck to the other, C and D (Fig. 2). He says that, by stopping the trunk end short, you are able to walk past E. We find that this part of the weather-deck (the trunk deck) is essentially the navigating platform of the vessel; and, excepting on special occasions, there is no need to be down at C (Fig. 2). I thoroughly endorse Mr. Hök's remarks regarding the high platform deck, and I think he has very pithily placed before you the natural benefits accruing

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from the design. It must be apparent to everybody here that, by placing these hatches F (Fig. 4, Plate XXIII.), which are on the top of the trunk, 6 or 7 ft. higher than this deck, which is the weather deck of the ordinary vessel, we have very much better arranged hatches; in fact, vessels so constructed can heel over many degrees further before the hatchways will come into the water. The safety involved in the principle must be apparent to everyone. Mr. Martell has spoken very forcibly with regard to pillars. I quite agree that a few pillars are necessary, and there is no doubt that pillars should not be entirely dispensed with. The only point which I suggest should be kept prominently in view, when proposing to reduce the number of ordinary pillars, is the fact that ordinary round pillars are attached, usually, by a couple of rivets on to the beams and lugs, and that these rivets are liable to become slack, due to the working of the vessel. Now the pillaring adopted in these trunk vessels, with the approval of Lloyd's, has been the adoption of these channel irons which Mr. Hök illustrates, which are enormously strong compared with the ordinary arrangements of pillars, especially when it is kept in view that the ends are attached with very strong bracket knee plates at the top and bottom, and well riveted, K, K (Fig. 4). I think if you dispense with most of the pillars, those that are left should certainly be in the nature of the pillars that Mr. Hök has illustrated in the drawings of the vessel *Oscar II.* Mr. Hök suggests that the plating may be left inside the trunk for certain purposes. I hardly agree with him that it might be desirable; in fact, I do not know that any owner would think of going in for a vessel with what would, practically, be a box erected on the deck. I do not think that this would be a useful design at all; the whole object of the design, I think, is destroyed, if plating is introduced in that position. These vessels are natural self-trimmers, and therefore by so doing, you will lose one of the great benefits of the type. We have eleven vessels now running, which, in ports in this country, do not pay a shilling for trimming their cargoes at all, except for trimming into the bunkers. In the first trunk vessel which we built, the only dues paid for trimming were for trimming coal into the bunkers in the centre part of the vessel (bridge). For the whole of the cargo space not a shilling is paid for trimming. If this is put into figures, I think that something like a saving of £100 or £130 on a large vessel is effected every time the vessel loads a coal cargo in a British port. That money, in these days, is a saving worth having. With regard to the shifting boards, we find that these trunk-deck vessels carry grain in bulk with very great success; the type certainly obviates, in my judgment, the necessity for shifting boards, and I hope with Mr. Hök that, ultimately, the Board of Trade will not require them to be fitted in "trunk" vessels. There is no actual necessity for them, all the surface movement of grain or like cargo which takes place is confined in the "trunk." If you consider this vessel as heeled over to the maximum degree, you will see that the shifting of the cargo must take place entirely within this "trunk," and, consequently, without endangering the stability of the vessel. With regard to the density of cargo, Mr. Hök has produced in the *Oscar II.* a very useful measure of capacity; we find from experience that a capacity which gives about 58 cubic feet to the deadweight ton, exclusive of permanent bunkers, is most useful. It is very extraordinary how this result can be regulated and produced either in big or small ships, entirely at the will of the designer of the vessel. We can get 58 cubic feet, and even greater than this, in almost all the vessels that we have designed of this type. I do not quite agree with Mr. Hök's statement regarding the cost to build, because, by experience gained in vessels we have built, it can be shown that (and I am quite certain Mr. Martell will excuse me saying so) there is not the slightest reduction in cost, at any rate in building to Lloyd's. In the vessels we have classed with Veritas and the British Corporation there may be a reduction in cost, but I think that is due to the difference in the nature of the rules rather than to the type of the vessel. It is a well-known fact that vessels classed with other registration

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societies are something less in their total weight; I think, therefore, if Mr. Hök found a reduction in the cost of building these vessels, that it is entirely due to the registration rules. Tonnage, Mr. Hök has mentioned very forcibly, and I think the type of the vessel really does lend itself, I will not say to evasion of the Board of Trade rules, but, shall I say, one can take full advantage of the Board of Trade rules. The Board of Trade,. I am sure, cannot take exception to anyone building, and complying with the strict interpretation of their rules, and I really think this design is a suitable one for producing vessels with very favourable tonnage indeed. I think Mr. Hök is quite right in suggesting that the design is such that, by manipulation of the "trunk" in various ways, the tonnage can be kept low; that, of course, is very useful in the designing of deadweight vessels. My remarks have been rather lengthy; but I will close them by drawing attention to the vessel illustrated on Fig. 1, which shows that this "trunk" vessel is sheered at the "trunk" top, with the same sheer as the sides of the vessel. This affords a prettier-looking vessel, and, when at sea, she looks like a "flush" or "spar" decked vessel. I do not think that there is much to be gained by making the top of the trunk horizontal with the keel; at any rate I think it is not quite so graceful-looking, and certainly not so efficient. I think by sheering the "trunk" you get a better appearance. With regard to loading and unloading cargoes, they certainly compare very well indeed with ordinary types of vessels. The vessel shown in Fig. 1 has loaded, alongside with others, timber cargoes, and taken almost two slings of timber to one of the other vessel. That is very important when despatch is considered. We find that, in the case of all descriptions of cargo, these vessels do their work famously. If it be a case of oil cargo, grain, cotton, rice, or any description of cargoes, they show a higher percentage per net registered ton than ordinary vessels, and have done their work marvellously, and gained a higher revenue than any vessels that we ourselves have pitted against them. Before sitting down I would say that we have proposed these "trunk" sides to be sloped or curved (Fig. 3, Plate XXIII.), in order to facilitate the flow of grain and the loading of such cargoes.

Sir Raylton Dixon (Member of Council): Sir William White and Gentlemen, I had not intended to make any remarks upon this paper, and, unfortunately, I only came into the room when it was half read, therefore I have not had time, not having seen it before, to look into it carefully. There are one or two things that strike me which I think Mr. Hök in his reply could enlighten us upon, particularly in regard to deadweight capacity in proportion to the tonnage which he speaks of, and for which he claims one of the great advantages for this type of vessel. Now, looking at the examples given in this paper, and I naturally presume that the instances they have taken are likely to be pretty favourable to the principles they are advocating, I find that the deadweight capacity, in proportion to the registered tonnage, is not so great as is very common in vessels of ordinary construction of a similar class: I mean cargo-carrying vessels. It is a common thing for such steamers to carry deadweight of 2·5 to 2·6 of their net registered tonnage. This is quite a usual and common thing; whereas, I find in the vessel given here, as a sample or specimen of the type of ship, that she does not carry as much as that, and, therefore, I can hardly consider that, with regard to that matter, there can be any advantage in the construction of the vessel which we are discussing. Of course, there are only two factors in this question of the carrying capacity. They are, the displacement of the ship and the weight of the vessel; and, as I understood from Mr. Hök—I might be mistaken—the increased carrying capacity was in consequence of carrying out in a scientific and very interesting manner the regulations of the Board of Trade. At the same time, Mr. Hök gave us to understand (on which point Mr. Ropner differed, and Mr. Ropner as a builder of trunk steamers is not likely to want to depreciate their prices or values in the face of the shipowners present) that there was about 10 per cent. less

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cost. I take it, if there is 10 per cent. less cost, or any such appreciable amount, that might mean that there is a certain percentage less of material in the ship—it might not be quite 10 per cent.—therefore the ship must be lighter; so that, if that is the case, the ship compares very badly with the ordinary trunk steamer in carrying capacity, as if she is of lighter construction as a ship she is still carrying less quantity in proportion to the tonnage. I must admit that I am speaking on a matter that I have not paid much attention to. I have not had the honour of constructing any vessels of this class; we have, perhaps, not got quite so far advanced at Middlesbrough as that yet, but I do not know what we may come to! I am glad to hear one thing (as I am somewhat conservative in my views), namely, that Mr. Ropner still claims to make the trunk steamer, as far as he can, like the ordinary, old-fashioned, respectable boat. He does not like to give away the sheer, because, he says, it looks better and more like another ship, so that he wants to make a trunk boat as much like a boat that is not a trunk boat as possible, and I wonder, when a new and valuable type of ship like this is being discussed, that he does not endeavour as much as he can to make it as *unlike* any other ship which has been produced before as possible, and to do away with the sheer. I believe there is one type of ship where the sheer is put in the other direction, and there are certainly very sensible grounds for that, as a question of mechanical structure. There is one other point I should like to allude to, and it is a simple one. They have spoken of the facility of discharging. It seems to me that the more feet of height you have to lift any number of tons the greater the power and the greater the time you must expend, and, if you have to lift all of that cargo over a trunk 7 ft. 6 in. above the deck, there must be more time and, certainly, more power required to discharge it. There is one other matter, and that is with regard to the trim which is claimed in the paper. The author says there is the advantage of being able to "trim by the stern even when loaded with homogeneous cargo throughout." I do not exactly understand why that should be, because, looking at the plan of the ship which we have before us, the principle of this trunk boat is that the trunk extends the whole length of the ship, and although we know in the after part of a cargo vessel there is the loss of space to be taken from the available space by the tunnel, and there is the difficulty sometimes with these cargoes of getting the full weight aft: I do not see how you benefit that by adding the trunk above, when you are adding exactly the same trunk above in the fore part of the vessel. No doubt Mr Hök will enlighten us on some of these things. I must apologise for having made these very casual remarks on this matter; but I think all these new types of ships are exceedingly interesting, and, no doubt, some do their work well. Questions of pillars, and that sort of thing, I hardly look upon as a matter of principle in this trunk construction. There can be as many or as few pillars put in a trunk steamer as in any other without interfering with the principles of construction claimed for this type of ship. The strength of the vessel, as we all admit, must be the long, continuous box girder, or something approaching it, formed by the trunk over the ship, which is doubtless a very great source of strength; but in regard to the other points, I should be glad if Mr. Hök, in reply, would let us hear what he has to say, and tell us how he explains these questions of the deadweight capacity in proportion to the tonnage, because I think, really, they are not taking as much advantage of the Board of Trade rules as they might: or else there must be something about this type of steamer that, unfortunately, does not enable them to do so. I apologise for trespassing on the time of the meeting.

Mr. Robert Thompson (Member): Sir William White and Gentlemen, I have been very much interested in this paper and the discussion, although I cannot go quite so far back as Mr. Macfarlane Gray went yesterday, and refer to a paper two hundred years old; I think it is thirteen or fourteen years ago since my firm got out a plan for this very shape of ship. It was suggested to us by a shipowner in Sunderland, and we went very carefully into the matter, but the question of cost deterred us from

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building this type. We estimated that she would cost much more than an ordinary ship. What Sir Raylton Dixon has said about cubic capacity and tonnage I can bear out fully. We have built any number of ships carrying over 2·5 times their net register tonnage measurement, and having cubic capacity space in proportion. Some of them were ordinary spar-deck vessels, and we have built one ship which carries 4¼ times her net register; but she is a special type of boat, the trunk, instead of being a box on the deck, is a trunk carried right down, for carrying pig iron. Mr. Hök, on this subject, tells us that he simply moves the side of the ship in. That reduces the depth. He says this is perfectly true. Supposing you reduce your ship 2 to 3 ft. at the side, and put a 3 ft. hatch or trunk on the top of the deck thus left, I cannot see the difference between the height of that ship and a deeper ship. As far as the question of superfluous buoyancy goes, if you carry the trunks further up you get more superfluous buoyancy; but, is it of any use? The superfluous buoyancy should be nearer the waterline. Then, as to the question of trimming, which both Mr. Hök and Mr. Ropner make a great deal of, my firm has built a large number of self-trimming ships. The hatches were spread out in some cases to within 6 to 8 ft. from the ship's side. Before the arrangement of wing-boards was carried out, some of those ships were lost, no one can tell how they were lost. The Board of Trade, naturally and rightly, insisted on wing-boards being fitted. With small-coal cargoes this type of ship ran themselves full. In the case of "trunk-deck" vessels, with small-coal cargo or grain, there must be a large space at the corners, formed by the deck with the sides of the ship, which is never full. If shifting boards are done away with altogether, it is not in the trunk where the grain or small-coal cargo will shift, it is in the wings of the ship, and I am quite sure that the Board of Trade will think twice before they allow shifting boards to be taken out of ships of this type, with a space that cannot possibly be trimmed up. Mr. Ropner says they do not do any trimming, and I should say the space mentioned above is never full if they do not, and, naturally, it would be a danger to a vessel of that type. Then the sheer of this ship is reduced—the sheer of the trunk—so that I think the ends of the ship, the after-hatch and the extreme fore-hatch, are at about the same height from the water as in an ordinary ship, and it is stated the seas do come over the vessel. With regard to the pillaring, I quite agree with what Mr. Martell says. We have built ships, broad and shallow, and, in my opinion, pillaring there is a great necessity—efficient pillaring. Then Mr. Hök says that, in the Bay of Biscay, "The seas are repeatedly washing over the main deck, and, I understand, the experience in turret-deck vessels is similar." In taking that paragraph as it stands, we should remember the experience with turret steamers. The first turret steamer began with no bulwarks—plain decks—and she was said to be perfectly dry. The turret of to-day, as Mr. Ropner put it, in respect of this type, is very nearly like an ordinary ship. She has bulwarks amidships, top-gallant forecastle, bulwarks round her stern, and, I take it, the seas washing over the turret would apply to this trunk ship equally as they do to a turret. The turret, as built to-day, is gradually approaching the ordinary ship. I think if we built a few of these trunk steamers the probabilities are we should find the same result. Then, as to the question of discharging so many tons per hour, I understand there is great difficulty in having a platform erected to discharge cargoes, especially with grain cargoes, which is weighed as it goes over the side. As soon as ever it lands on the quay it belongs to the merchant, and the shipowner's control over it ceases. While it is on the ship the captain has control over it; but, when it is on the quay the ship loses all control of it. Mr. Hök gives here one hundred and thirty more tons per day for ore cargoes, and Mr. Ropner says they discharge the ships very quickly. That is a question of winches and derricks. How many derricks are there in these ships? According to what I know of these ships they are pretty well supplied with derricks and winches, and to compare them, having these extra

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appliances, with a ship which has only four derricks and four winches I do not think is quite fair. The question of rapidity of discharging is simply a question of the means of discharging. The cargo has to be lifted over the trunk, and means have to be on the deck for passing it over the ship's side, which certainly cannot be done with anything like the rapidity obtaining in an ordinary ship. I do not think I have anything more to say, except that I can confirm what has been said with respect to the deadweight and cubic capacity, and I should not be afraid to build an ordinary cargo boat at the same cost as a trunk steamer, and I am perfectly sure that anyone working on the plain-deck ship can get about that ship more readily than when it is all up and down stairs as these new types are.

Mr. H. F. Swan (Member): Mr. Chairman and Gentlemen, I had not intended to speak upon this paper at all, in fact I had not seen it, and I have not yet read it; but, having merely glanced over it, and having seen the drawings and heard the remarks that these gentlemen have made, I cannot help being struck with its similarity to the ordinary oil steamer. This section here, to my mind, if you omit the double bottom, is nothing more nor less than the tank steamer that we have been building since 1885. In fact, I see on page 71 that one of the points claimed is that "the trunk forms, then, in conjunction with the holds below, one large cargo space" (Fig. 1, Plate XXI.). It is evident that such a construction provides, without further modification, an excellent natural feeder to each hold for such cargoes as grain, coal, oil, &c. I may say, when I took out the patent in 1885 for such a ship, and applied in Germany for a patent, they would not give me one, and said this feature which you have here is nothing more nor less than what is regularly done in grain ships by boxing round their hatches. The continuous trunk I claimed at that time as being an item which gave great strength to the ship. I have always made them parallel to the sheer, and I have also often built vessels with the trunk on deck continued to a certain distance; but, on the whole, I prefer the continuous deck with the sheer, because I think it gives strength and has many other elements of advantage. For these reasons I cannot criticise this design. I believe it gives a very satisfactory ship for the purpose for which it is intended; but, as I say, it is nothing more nor less than a tank steamer in another form. The pillaring and the construction is all what we have been in the habit of doing for a great many years.

Mr. W. Hök (Member): Mr. Chairman and Gentlemen: Mr. Ropner has replied to so many of the points referred to by Mr. Martell, and, further, the question of pillaring is so fully treated in the paper itself, that there are very few points for me to deal with. As regards the cost of this particular steamer, I have stated in my paper that the cost thereof is about 8 to 10 per cent. less than that of an ordinary steamer carrying the same quantity on the same draught, and built either to Lloyd's or Veritas rules. That, I think, is so, and is simply due, as Sir Raylton Dixon remarked, to certain minor reductions in the scantlings of the vessel, due to a better disposition of material, without sacrifice of strength, enabling you to build a vessel of reduced size for the same carrying capacity, and of less weight and cost as a matter of course. I do not think, and I quite agree with Mr. Ropner, that if this type of ship was classed with Lloyd's, she would be any cheaper than an ordinary steamer, for reasons I need not go into. Mr. Ropner also referred to the top of the trunk being straight. There are certain reasons for this, and one is that depth of girder is advantageous in the middle, and not required so much at the ends. By making the trunk straight you get a deeper girder in the middle and a shallower girder at the ends than if the trunk had sheer, which reduces the weight of hull a certain amount without sacrifice of strength, and this is, of course, an advantage. There is another reason why the trunk is made straight, which is, as Mr. Ropner hinted at, that you can take some slight advantage of the rules for measuring tonnage. You can reduce the tonnage slightly by

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making the trunk straight. Sir Raylton Dixon asked the reason why ships of the type here described always trim by the stern. Those drawings which are hung so prominently on the wall, and which everybody has referred to as my drawings, are Mr. Ropner's, not mine. In order to show clearly the reason why this type always trims by the stern, I may point out that it is quite evident, when the main sheer forward exceeds the main sheer aft, that you get more capacity in the trunk aft than forward, when sheer of trunk is straight; this extra capacity in trunk aft over trunk forward causing these ships always to trim by the stern. That is the simple reason.

Sir Raylton Dixon: That is dependent on the trunk being straight, not sheered as shown there.

Mr. Hök: These are Mr. Ropner's drawings, and not mine. If you refer to the illustrations at the end of my paper you will find that the top of the trunk in this type is straight. As regards the ratio of deadweight to tonnage, it is quite true that this ratio is not exceptionally high in this particular ship, but I must remind you that this ship carries 5,500 tons, or, if she were made into an ordinary plain tramp steamer, about 5,600 tons, on 20 ft., and I do not think you will find many ships built which carry 5,500 or 5,600 tons on 20 ft. I do not think that ordinary ships built to carry this quantity on 20 ft. would show a higher proportion, or even an equally high proportion of deadweight to net tonnage, than I show in this steamer. This also covers Mr. Thompson's remarks in connection with this point, and I think, if Mr. Thompson refers to the ships he had in his mind, he will find they are either smaller ships, or ships carrying 5,500 or 5,600 tons on 22 ft. to 23 ft., and then it is quite possible to attain this high figure, or even a higher figure, with an ordinary steamer. The reason why the ratio of deadweight to tonnage is relatively low is that this vessel is a large vessel of shallow draught for her capacity, and of extreme proportions. As regards the shifting of cargoes, if there be no grain or coal in the corners under the main deck next to the sides, and the trunk is full, it is quite evident that, when the ship has rolled a few times from side to side, these two empty corners under the gunwale will be filled up with grain from the trunk, and I therefore think there is no force in that objection. As regards Colonel Swan's remarks, we all know that oil steamers have been built for a good many years of a somewhat similar construction, but there surely can be no objection to this steamer on that score. However, I think you will find if you investigate the matter that there is some difference after all. Even if this steamer is not fully original, it may be a useful type, and I trust it may be a successful one too. I do not think I have anything more to say, except to thank you all for your kind indulgence.

The Chairman (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Gentlemen, I am sure you will all wish to join in a vote of thanks to Mr. Hök for this interesting paper, which has provoked an equally interesting discussion. Many men of ability and experience are always striving after improvements and increase in earning power for merchant ships. This may involve evasions of certain laws for tonnage, or the scientific utilisation of existing rules for scantlings, or may produce improvements in construction or changes of type. In this Institution we are always glad to learn the latest practice, and we are much obliged to gentlemen who give us the benefit of their experience. If I may be permitted to make one remark, not in the way of discussion, but as a personal opinion, I would say that, while I entirely agree with what Mr. Martell said with regard to pillars, yet there can be no question that, when we have strong girders both at the bottom of a vessel of this construction and at the top, we can afford a wider spacing of pillars if they are individually very strong and well attached. I have had some unpleasant experiences myself when pillars have been omitted, although included in the building drawings and specifications; and, in single-deck vessels such as these, no doubt pillars must play a most important part in the structural strength.

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ON RESISTANCE TO THE MOTION OF SOLIDS IN A FLUID.

By Mr. B. Schieldrop, of Bergen.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 31, 1898; Sir William White, K.C.B., LL.D., D.Sc., F.R.S., Vice-President, in the Chair.]

It can hardly be disputed that the efforts which have been made, to discover the magnitude and character of those forces of which the total resistance to the motion of solids in a fluid is composed, have not been very successful.

As long as the hypothetical conditions of a solid passing through a frictionless and absolutely incompressible fluid are considered, the deductions of the modern theory of resistance are incontestable. But, taking into consideration the actual conditions prevailing in a fluid which, like water, is compressible—even if it be but slightly so—and the particles of which oppose a relative motion by friction, then a field of a very different character has been entered, and the gap which separates these two fields is a very wide one, and has proved to be a very difficult one to bridge.

The stream-line theory, which has been very commonly accepted by naval architects, and the wave-line theory, based upon it, are admittedly not perfect, but open to objections in several important respects, when actual conditions are considered:

In the first place, the stream-line theory is not established upon elementary, clear, and indisputable facts;

In the second place, it does not, in a satisfactory manner, account for all observed phenomena; and

In the third place, it does not—neither in kind nor degree—give satisfactory and clear answers to those questions which the naval architect must know, to be able to design intelligently the wetted surface of his ships.

Moreover, it seems that one circumstance, which, in the estimation of the writer, occupies a central and very important position in the problem, has been ignored, or at all events obscured, by the stream-line theory: Let the solid shown in Fig. 1, Plate XXIV., be given an even motion in the direction of the straight arrow, and let it be so far submerged below the surface of the water that no surface disturbances are created

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by this motion. During a certain interval of time the solid will change its position from the one shown in dotted to the one shown in full lines. If the space under consideration is divided by a transverse plane X X, immovable with reference to the outside undisturbed water, there must, during the time interval mentioned, have been removed from the space to the left of X X a quantity of water a, and an exactly equal quantity b must have found its way into the space to the right of this assumed plane. As neither of these spaces has altered its boundaries during this time, and as water is practically incompressible, the only possible conclusion must be that a quantity of water $= a = b$ has, during this time interval, been flowing through the dividing plane X X in the opposite direction of the one in which the solid is advancing. This flow, which is a function of the midship section and the velocity, takes place in a fluid which is not perfect—not frictionless—consequently energy is consumed by it, and, be this loss great or small, it cannot be placed under any of the three heads: skin friction, eddy-making resistance, or wave-making resistance.

In consequence of this flow, the relative velocity of the solid and the water which immediately surrounds it, must be greater than its absolute velocity in relation to the outside undisturbed water; and this circumstance must, necessarily, have some bearing upon the magnitude of skin friction.

It is not, however, intended here to enter into any extended discussion of existing theories; but, on the contrary, to point out that, in the absence of elementary, clear, and indisputable facts upon which to base these theories, any suitable criterion for their profitable discussion is also wanting.

Such facts, adapted for a rational, scientific inquiry of the subject, have not been supplied by measurements of the total resistances on solid models. The experiments conducted upon models of ships by the late Mr. Froude have undoubtedly been exceedingly valuable, in so far that they have been directly applicable to the determination of lines for certain hulls; but, each experiment must occupy an isolated position, the chain or law which should make a grouping or combination possible being out of reach.

That this want will ever be supplied by accumulated information about total resistances is hardly to be expected; and this doubt may perhaps be illustrated by making a comparison with another branch of physical research, where efforts have been more successful. If we—while not possessing any knowledge about the strength of materials, and the law of the parallelogram of forces—had, in some way, inherited from our fathers a number of complicated bridge designs; and, at the same time, our only access to further knowledge on the subject was limited to the testing of these bridges to destruction; then the probability of ever placing the strain sheet within our reach would be very slight indeed. And—as to the case in hand—when our only source

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of information is the measurement of total resistances which are made up of several components, depending for magnitude upon so many varying conditions, we are not more favourably situated than in the case assumed above.

The dynamic forces, of whatever nature they may be, by which the fluid resists the motion of a solid, must be transmitted through the skin of the solid. And whether it is intended to furnish the naval architect elementary information about the degree in which the different parts of the surface contribute to the total resistance, and the manner in which varying qualities of the surface influence the magnitude of these contributions; or, it is desired to secure facts suitable as bases for scientific inquiry of the natural phenomena attending the creation of these forces; it seems natural to the writer that efforts should be primarily directed towards obtaining full information about the actual magnitude and character of the forces to which the various parts of the skin are submitted.

And if it was possible to measure these forces, and subdivide them in homogeneous groups, so as to permit examination and study of each separate group, this information would, undoubtedly, be the means of solving most of the important questions relating to this subject which are at issue at present.

It is the object of the present paper to point out a method by which it is hoped experimentally to secure information of this character about these forces.

These experiments it is proposed to conduct in two series. But before entering into the practical questions involved in the construction of models and recording apparatus of which it is proposed to make use for these experiments, it will be attempted to examine briefly the character of the information which it is hoped to obtain.

The models for Series I. (see Fig. 2, Plate XXIV.) will have a cylindrical middle-body, and the longitudinal sections of ends will be bounded by strictly mathematical curves. This, principally, to be able to give brief and still exact information of their forms, and to facilitate computations which will have to be based upon these forms. Character of surface and degree of smoothness to be of the same standard kind, to facilitate easy reproduction and description. By these models it is attempted to obtain automatic, continuous records of resistances parallel to the axis for varying speeds *separately* for each of the three parts A, B, and C, which, according to common opinion, contribute components of very different magnitude and character to the total resistance. During a set of experiments with each model it will be towed at different depths below the surface, including the position in which the longitudinal axis coincides with the surface of the water.

The middle-body B of these models will be subjected to static pressure as a normal force; and if other forces of this character are created by the motion, they will

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have no influence upon recorded resistances, because they will have no components in that direction. If there should arise any oblique forces on account of the motion, the longitudinal components of these forces would be recorded, together with the skin friction. But if forces of this character have come into existence this will first be ascertained by experiments under Series II. Otherwise, this part B should presumably be submitted exclusively to skin friction; and by altering the character of surface, its length, &c., there will be supplied material for the study of this particular kind of resistance, as it actually exists in a solid, approximately ship-shaped body, and on parallel surfaces placed among curved ones.

As the separately recorded resistances of the ends are of a composite nature, containing—like the total resistance of the body—two, or perhaps more, groups of forces of different character, it may appear that, by this series no considerable advance has been made towards the desired end; namely, a subdivision of the resisting forces into homogeneous groups. But, if the dynamic forces may be divided into but two groups, one acting normally to the surface and the other parallel to it, it may be demonstrated that there is a strong probability of securing satisfactory information about these groups by a judicious change of the models of this series alone. This demonstration will not be attempted here, however, because it is expected to secure the necessary supplementary information, by which to obtain a firmer hold on these forces, by experiments under Series II.

Some very important questions will, at any rate, be answered directly by Series I. To what extent the three parts contribute to the total resistance, and how this relation varies by varying speeds, will be made plain. By alterations in form, it will be seen, if any certain change has a general, or merely a local influence. If, for instance, the resistance of part C be independent of the shape of part A, or the distance between these parts, as decided by the length at middle-body B. Moreover, if the point at which surface disturbances set in is carefully observed, it will be made manifest how, to what extent, and upon what part of the model, the wave-making influences the resistance. After a few experiments of this series it will be made very plain whether the stream-line theory in its main teachings is correct, or not: whether there is a resistance due to form—as represented by records of the ends—at the lower speeds, and before surface disturbances are created.

The principal object of this series of experiments is, however, to secure material for the study of skin friction, and, as to the ends, to obtain a control, or test, upon the accuracy of returns of Series II.

By the Series II. it is desired to obtain continuous records of the magnitude, direction, and location of the resultant of all the exterior forces to which integral parts of the surface are submitted.

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For this purpose the part under consideration is by longitudinal, radial planes divided up into a number of—say, ten—sections. Each of these sections is by anti-frictional bearings (see K_1, K_2, and K_3, Plate XXVI.) prevented from all motion except parallel to a longitudinal, radial plane through the centre line of the section. In this plane the resultant W_r (see Fig. 3, Plate I.) of all the exterior forces, in which the static pressure would be included, will be met by the three reactive forces R_1, R_2, and R_3. Of these, R_1 and R_2 act perpendicularly to the axis of the model, and a continuous record of their magnitude at varying speeds is secured. While R_3 acts parallel to the axis, and is not measured. It equals, however, the resistance obtained by Series I. for corresponding experiments. W_r may be considered decomposed into a parallel component $W_h = R_3$; and a perpendicular component W_p. O_1 must be the point of intersection for all of these three forces. For a state of equilibrium the following equations would then obtain :—

$$W_p + R_1 + R_2 = 0$$

$$W_p \times (l - X_1) + R_1 l = 0$$

By these two equations the two unknown quantities W_p and X_1 may be determined, and hence the perpendicular component of the resultant W_r, and the location at the point O_1 made known. If the same experiment is repeated with all conditions unchanged, except that the position of R_3 is changed to (R_3), we would obtain two new equations, exactly similar to those already stated, with the exception of X_2 being substituted for X_1, and by which the location of the point O_2 would be determined. Thus we have fixed two points through which the resultant must pass, the direction of both of its components, and the magnitude of one of them. Consequently the resultant W_r can be determined as to magnitude, location, and direction. And, as an extra test upon the correctness of results, we have the returns from corresponding experiments under Series I.

Let a model for Series II. be submerged to a certain depth below the surface of the water. Any section of its surface would then be subjected to a static pressure P_0 (see Fig. 3). This force P_0 would be recorded, and the correctness of the record might in this case be tested by computation, all the necessary data being at hand.

Let it be assumed that all the exterior forces are subdivided into two groups, namely : *normal* forces, in which the static pressure is included ; and *parallel* forces, including skin friction. Existing oblique forces will be represented by their components in these two directions.

If the dynamic normal forces were evenly distributed over the surface, then the resultant of all normal forces would maintain the position and direction of the static pressure P_0, which passes through the centre of gravity of the surface. It is, however, generally assumed that these normal forces depend upon the obliquity of the surface

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to the line of motion*, and, if we could assume a speed at which the normal force acting upon the extreme forward part of the section—the most oblique part—alone would be so great, as to make the normal forces acting upon the other parts of the section insignificant in comparison, then this force (P_{lim}) would become the resultant of all the normal forces. This (P_{lim}) is the limit of the forces of this order, which limit, however, never will be closely approached. The angle a expresses the limits within which the resultant of the normal forces may vary as to direction; and, as this angle is considerably less than the half of the opening angle of the body, and, moreover, as its higher limit never will be closely approached, it will be seen that this resultant cannot be subject to great changes as to direction. It will further be obvious that there must exist a certain relation between the three qualities of this resultant: a change in location must be attended by a corresponding change in magnitude and direction.

If the parallel forces—which, presumably, chiefly consist of skin friction—were evenly distributed, the direction and location of the resultant of these forces might be ascertained by computation; and these two qualities would not be altered, whatever the magnitude of these forces may be. In this case the resultant—indicated by F_0 on Fig. 3—would be perpendicular to P_0. It is, however, assumed that these forces (skin friction) are more heavily distributed towards the cut-water;† and employing a similar reasoning to the one used above, F_{lim}, being a tangent to the extreme forward part of the section, would become a never closely approached limit of their resultant, as far as direction is concerned.

If, at a certain speed v, a resultant W_v of all exterior forces has been found, it will be possible, by the aid of the reasoning just employed, to determine with close approximation the direction of its components F_v and P_v; and hence the magnitude of these forces would also be determined with a corresponding degree of accuracy.

F_v may then be compared to a corresponding quantity, derived by computation from experiments upon the middle-body under Series I.; allowance being made for a closer proximity to the cut-water. If this comparison should bring discrepancies to light, unexpected forces have probably been at work.

P_v may be decomposed into its components P_0 and P_n, the latter being the resultant of all the dynamic normal forces; and its magnitude as well as direction and location may be ascertained either analytically or graphically (as shown).

By changing the character of the surface on this model, leaving form and all other conditions unaltered, a corresponding change in F_v should be recorded, while P_n should remain as before. If records disappoint this expectation, it shows that a change in the

* Beaufoy's and Joëssel's experiments. † Mr. Froude's experiments.

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character of the surface creates oblique forces, or has an influence upon already existing ones, and that the subject even of skin friction is a far more complicated one than might be expected. But by the same means by which the existence of such oblique forces have been detected, their magnitude and character may also be determined by accumulating information.

To carry this inquiry any further at present would, however, hardly be profitable, if the effort has been successful to prove that, through the information about the resultant of the exterior forces, as to magnitude, direction, and location, means have been acquired by which each homogeneous group of forces may be singled out for itself; making possible a detailed study of each such group, as to its particular nature, variation with speed, dependence upon certain conditions, &c.

The writer believes it is merely expressing an axiom to say that such subdivision or grouping of homogeneous forces is an indispensable foundation for an intelligent discussion of this subject, and a necessary condition for a scientific treatment of the phenomena involved. This is, moreover, in full accordance with experience gained on other fields where complicated questions have to be dealt with. The efforts must be to eliminate from the inquiry, as far as possible, all except those influences which at any time are under consideration.

In describing the leading features in the construction of the models and recording apparatus, of which it is proposed to make use for these experiments, the reservation has to be made that the drawings have been prepared exclusively for the purpose of illustrating the present paper. Hence the object has been to show, as clearly as possible, the principal parts of the construction, without making any special efforts towards obtaining the best possible details, or a correct proportioning of parts.

The manner in which it is proposed to tow the models is shown in Fig. 4, Plate XXV. On a frame built of mild steel a platform is erected in the bow of the steamer, on board of which the recording apparatus is arranged. From this platform, which, to a great extent, is open, the models and surface-disturbances may be kept under close surveillance during the experiments. In this position it is also expected that the models will be best kept outside the disturbing influences produced by the steamer.

The models for Series I. will first be described.

The three parts A, B, and C (shells) are mounted on a hollow steel shaft D, Plate XXVI., of such radius that its deflection by the loads it has to carry will be kept within very narrow limits. It is possible that the stiffness of this shaft may have to be reinforced by stays.

A concentric position of shells and shaft is maintained by radial rods *a*, and a relative rotary motion is prevented by tangential rods *b* (see Section Z Z, Plate XXVI.).

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The ends of these rods are finished with sharp edges, which rest in grooves, so as to permit a longitudinal motion of shells with relation to shaft with the least possible resistance, while, at the same time, any other relative motion is prevented. The longitudinal forces to which each part of the shell may be submitted are, in the manner shown, transmitted to the flanged sleeve a_1, which, by the arrangement shown in section on the model for Series II., Plate XXVI., is given only a very small play longitudinally.

The shells are mounted on light metal frames, which, for Series I., are rigidly fastened to angular rings. Over this metal frame is drawn a strong but thin and flexible rubber coat, which extends from each of the solid extreme ends of the model to the middle-body, and which has been given a form closely conforming to that part of the model which it is intended to cover. By this rubber coat a water-tight and flexible covering has been provided for the narrow apertures ($\frac{1}{10}$ to $\frac{1}{20}$ of an inch wide) which separate the shells of the ends from the solid ends and the middle-body. Outside the rubber coat a wooden covering is neatly applied, fitting closely to the raised edges of the metal frame. And between the surfaces thus provided the rubber coat is pressed, so as to prevent water from entering under the wooden covering.

The object is now a threefold one:

In the first place, it is desired to have spiral springs S—one end of which set up against flanges on a_1—which at any time, while an experiment is carried on, exactly counterbalance the longitudinal forces transmitted to these flanges from the shells.

In the second place, to obtain on board the steamer, by which the model is towed, an accurate continuous record of the varying lengths of the springs. Having beforehand ascertained the forces which the springs will develop corresponding to any variation in length, the resistances would at any time be obtainable.

And, in the third place, to obtain an accurate record of the velocity of advance of the model.

To obtain these objects it is intended to proceed in the following manner:—

In each of the three parts a very small electric motor F is suspended from the shaft. These motors are all fed from a storage battery on board the steamer, through a common conductor and return wire insulated in the cable indicated on Fig. 4. Each motor acts through a gear upon a screw F, on which a nut with suitable flanges forms the support for the other end of spring S. On their way to the motor the electric conductors pass through an electric switch G, which is fastened to the shaft, and operated by the shell through the longitudinal motion of the flanged sleeve a_1. This switch has three positions. When a_1 is placed in the middle of the space which it—by limitations already mentioned—is permitted to travel, the switch will prevent the passage of any current to the motor. But, when this neutral position is passed ever so little in either

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direction, the current will be fed to the motor. If a_1 is pressed in its neutral position against the spring, the switch will cause the motor to revolve in such a direction that the spring S is compressed, and as soon as a_1 comes slightly forward of its neutral position, rotation will take place in the opposite direction, and the spring be permitted to lengthen. Accuracy of results will, in a great measure, depend upon the sensitiveness of this switch, making the motor respond to the slightest change in position of the flanged sleeve a_1.

As the exterior forces which it is desired to record by this series of experiments will be directly transmitted to the flanged sleeve a_1, it will be seen that there is a steady tendency, while the current is on, to make these forces counterbalance the pressure produced in the spring S.

The lengths of the spring S will be recorded upon a continuous strip of paper some 15 or 18 in. wide. This paper—record sheet—is given an even motion across a table on board the towing steamer. To each spring S corresponds a pen, or pencil-point, which is supported in suitable guides, permitting the points to move in a direction transverse to the one in which the paper is moving. The motion of each point is actuated through a screw, by two sets of electro-magnets, in such a manner that the point will move a certain, very small, distance to the right for every beat of the one set of magnets, and an equal distance in the opposite direction for every beat of the other set. These magnets are again operated by a galvanic battery, and are, by insulated electric conductors, carried through the cable and hollow shaft, connected to switches G and suitable contacts arranged on one of the gear wheels, connecting the electric motors with the screws F.

For every twentieth part of a revolution of the screws F, a contact will be made, and the corresponding pen, or pencil-point, will move a short distance on the paper; while the position of the switch G will determine whether this motion shall record a certain lengthening, or a shortening, of the spring; viz., a reduction, or an increase, of the exterior forces to which the part in question is submitted at the time.

To record the velocity of advance, three logs, somewhat as illustrated in Plate XXV., are employed. They are mounted together on a common frame, and towed from a pole extending horizontally out from the steamer, near the surface of the water, and so far ahead that the logs are kept outside the influence of the diverging waves in the bow. (See Figs. 5 and 6.) To each of these logs lead two insulated wires, between which a contact is made for every revolution of the propeller. Each log has its separate circuit, in which is placed a galvanic battery, and an electric magnet operating a needle-point. Near one of the edges of the record sheet (see Fig. 7, Plate XXV.) four columns are arranged. Of these each log has its own, and for every revolution of the propeller the needle-point will make a mark in the corresponding column.

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In the fourth column a needle-point will make a mark at intervals of 5 seconds.

The distances represented by one revolution of a log have to be ascertained by repeated runs at various speeds over a measured mile. By a comparison between the distances represented by the log marks, and the space they cover in seconds, a record of the velocity of advance is obtained corresponding to the resistances recorded in the middle portion of the paper.

As already stated, it is intended by Series II. to measure the lateral forces to which the shells are submitted for the purpose of ascertaining the resultant of exterior forces.

In the models for this series the parts which it is intended to investigate are, by longitudinal radial planes, divided into sections, and each of these sections is by antifrictional bearings K_1, K_2, K_3 prevented from any motion except in a direction parallel to a longitudinal radial plane through its centre-line. Motion in this plane is further limited, roughly, laterally by tongues and grooves in bearings K_1 and K_3, and longitudinally by rods m and the fixed ends of the model.

All joints are made water-tight by the rubber coat already described.

As soon as the model is submerged in water, the longitudinal component of the static pressure will be transmitted through arms M and N and rods m (Plate XXVI.) from shell to shaft. By these members the reactive forces R_3 are carried. To insure that these forces are transmitted in a parallel direction to the axis of the model, the rods m are provided with sharp edges at one end, while the other end, which is finished as a circle, the radius of which equals the length of the rod, rests against a plane surface exactly normal to the axis of the model.

By the construction, all the dimensions corresponding to the quantities l, h_1 and h_2 will be known, and by the previously submitted analysis it has been shown that all the forces which it is necessary to measure, to learn what is desirable to know about the resultant of the exterior forces, are the reactive forces R_1 and R_2.

These forces are transmitted through radial rods a, which are provided with broad edges at both ends, to angular levers, and from these further by longitudinal rods to flanged sleeve a_1, which forms a part of the measuring apparatus previously described, and by which these forces R_1 and R_2 will be recorded in exactly the same manner as under Series I.

All the sections into which the shells are divided under Series II. must be very accurately balanced as to weights, and not merely as to their total weights, but also as to their distribution upon the reactive points a, a. If this be attended to these weights need not be considered any further during the experiments, because they will have no influence upon the recorded forces. The weights of exactly opposite sections will

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balance each other; the weight of the upper one being added to, and the weight of the lower one being deducted from, the exterior forces acting on each part.

On the drawing, the shell of the middle body of the model for Series II. is shown rigidly fastened to the shaft by a substantial frame. If it should be found desirable, however, to ascertain if this part is submitted to any dynamic forces which are not parallel to the surface, a similar arrangement may be made for this part, as shown for the forward end, with such modifications as the difference in form may occasion.

The static pressure will, in all cases, but more especially at small speeds, be the most prominent component of the recorded forces. Hence the dynamic forces have to attain a considerable magnitude, before their influence upon the resultant becomes strongly perceptible. Moreover, the springs will be greatly compressed by the static forces, before any dynamic forces come into existence, and these have then to be recorded upon springs which are far less responsive to slight changes in the acting forces, than would be the case if the springs had been partly relieved from this static pressure. It is a matter of course that these circumstances, in a great measure, will injure the accuracy of recorded results.

This difficulty it will be possible, however, to obviate almost entirely by filling the inside of the model with compressed air, of such pressure that it nearly, or entirely, counterbalances the static pressure on the outside. For this purpose the inside of the model should be kept in continuous communication with an air tank on board the steamer, through the hollow shaft D and a line of pipes, which has to be flexible for a short distance near the model to permit adjustments of its depth below the surface of the water. The pressure of the air is to be recorded by a gauge kept under close observation while experiments are in progress.

The model, being secured to the towing steamer with its longitudinal axis originally horizontal, will have this position altered, if the steamer, at different speeds, alters its trim. By suitable instruments this change of trim must be recorded; because, any deviation from the horizontal position will add new forces—components of the buoyancy of the model—to the recorded results. And to be able to introduce proper corrections for these forces, they must be known. In Series I. these forces will, with a very slight deviation from the horizontal, attain a considerable magnitude; because here the component of the buoyancy parallel to the axis—in which direction the forces in this case are measured—will vary with the sine of the angle of deviation.

Absolutely smooth and undisturbed water is an essential condition for successful results. And, in passing, it may perhaps in this connection be proper to state that the writer has one of the narrow, well protected "Fjords" of Western Norway in mind, as a suitable place, where the most desirable conditions, probably, will be found for the conduct of these experiments.

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The experimentalist takes up his position in front of the record-sheet, and by speaking-tubes he is kept in constant communication with an assistant on the platform in the bow, the officer in charge on the bridge, and the engineer in attendance. Any occurrence which may be thought in any way to have an influence upon the results is at once communicated, and a brief note made upon the record-sheet itself, which the experimentalist is keeping under personal observation.

The models, the recording apparatus, the logs, &c., are to be considered as scientific instruments; and in consequence of this the perfection of the design in all its minutest details must be carried out with the utmost care and best available advice; the workmanship and materials must be of the most select character; and upon the adjustment of the instruments must be bestowed a considerable amount of patience and good judgment.

The main features involved in the construction and use of the models, recording apparatus, &c., have here been briefly presented; and the object has been chiefly to prove that the task of ascertaining the magnitude and character of those dynamic forces, to which the skin of a solid passing through water is subjected, is a possible one.

But, it is admitted, that to furnish an opportunity for judging correctly the ultimate value of the present proposition it is not sufficient to prove that the task is possible; because the value in this case will, to such a considerable extent, depend upon the accuracy of the results obtained. Success in this respect will, however, in a great measure be a question of details; and an extensive treatment of details will necessarily be limited by the scope of a paper like the present. Moreover, the writer believes it very improbable that such details will be made in every way satisfactory before some lessons have been furnished by actual attempts.

If it is attempted, at present, to form a judgment of the accuracy to be expected from these experiments, three points should not be overlooked:

In the first place, the records are continuous, and we may be certain that the natural forces which we are attempting to investigate, when correctly recorded, will be represented by very even curves; while almost all disturbing influences will lack continuity; and hence disclose their presence by suspicious, and, more or less, abrupt breaks in the evenness of the record.

In the second place, when a model has been placed in position and adjusted, it will take, comparatively, but little time and effort to repeat an experiment any desired number of times. And the number of returns is a factor of accuracy.

And, in the third place, the experiments are conducted in two separate series, of which the one provides a test upon the accuracy of the other. Disagreements between

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corresponding results in the two series will not merely disclose the presence of inaccuracy; but, most probably, give some indication both as to the magnitude of the error, and in what quarter it must be looked for.

It seems reasonable to expect that the results of these experiments should prove very appropriate as a basis for a comprehensive and profitable discussion of this subject. These results are excellently well adapted for general publication; and by certain letters and numbers of reference attention may be fixed upon:—

(1) A certain model of sharply defined form, dimensions, and character of surface; simple enough to be easily held by the mind, while a comparison is being made; and

(2) Certain graphically presented curves of resistances corresponding thereto.

One circumstance of considerable importance deserves to be mentioned here, namely: the results will go forth directly, without having to pass through any person's mind for digestion or translation; by which process personal views might easily be confounded with direct returns. The function of the experimentalist is exclusively to obtain correct results, and present them in clear and intelligible forms.

The task of securing this information will, however, neither be a quick, an inexpensive, nor an easy one; and the questions to which a competent criticism is invited are:—

In the first place, are the facts, which it is here expected to learn, sufficiently important to warrant the cost of securing them? And,

In the second place, are the methods, here briefly outlined, found sufficiently practicable and promising to warrant the attempt?

DISCUSSION.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President), during the reading of the paper: We all admire Mr. Schieldrop's knowledge of English, not only in having written the paper, as he has done, but in having now reduced it to a briefer form *viva voce*, as time was limited. I would now suggest that the rest of the paper should be taken as read and the discussion commenced. There is a gentleman present who has had the opportunity of reading the paper, and who also has the great advantage of having been well acquainted with Mr. Froude's methods of experiment. I will now ask Mr. Morrish to commence the discussion.

Mr. S. W. FURZE MORRISH (Member): Sir William White and Gentlemen, I had the honour and the pleasure of reading through this paper a few days ago, and I think we must congratulate Mr. Schieldrop on putting his ideas into such a very interesting shape, especially those which deal with the experiments he describes under Series II. I take it, from his paper, that the main object of Series I.

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is to establish the truth of the stream-line theory; but I think if he had been here yesterday and had heard Dr. Hele-Shaw, and had had a little further acquaintance with what has been done in the past, especially by Dr. Froude, he would not have been so doubtful about the stream-line theory as he appears to be. The principal feature is that he takes a model, divides it first of all into three longitudinal portions, and then further into ten transverse sections, so that we have a model, somewhat in the shape of a torpedo, divided up into thirty sections. He proposes to try and find the position, magnitude, and direction of the resultant force on each of these sections, and then to split up that resultant force into its components in the usual planes of reference. There is a long description about the method of recording electrically and automatically the speed, both of model and water, in relation to the ground, by means of three small log screws, a clock, and a continuous drum of paper. There is nothing novel in all this; it is, in fact, quite common, so also is the method of mounting the model at the bow of a ship, I think it is meant to be. These, of course, are quite matters of detail, and do not affect the main object of the experiments. Probably a better arrangement than that here described might be found, but the part of the paper which is particularly interesting, and clearly illustrated in Plate XXVI., is that dealing with the experiments under Series II. There is one point about which I should like to ask Mr. Schieldrop. I take it that, to get any trustworthy results from the experiments which he proposes, it would be absolutely essential that each of these sections should be properly balanced. They should be each of exactly the same weight, and their centre of gravity would have to be symmetrical about the axis of the model.

Mr. SCHIELDROP: That is mentioned.

Mr. MORRISH: The difficulty of obtaining this, I fancy, Mr. Schieldrop has rather under-estimated; but, if we are able to get any reliable measure of these forces, it would be a great advance. As far as I can make out, the models are intended to be entirely submerged, and are not run anywhere near the surface.

Mr. SCHIELDROP: They were running at different depths.

Mr. MORRISH: At the same time they were completely submerged.

Mr. SCHIELDROP: Including the position where the axis coincides with the surface of the water.

Mr. MORRISH: The result would then be more complicated, and we should have to take into account the wave-making resistances. I thought that the principal object of the paper was to get full information about the skin-friction forces quite apart from the wave-making ones. If the surface is broken, the problem becomes much more complicated. No experiments, as far as I understand, have yet been made with any models built and tried in the way here described; but Mr. Schieldrop has put his ideas into shape with a view to someone taking it up, and so giving us the information which he thinks might be obtained. This paper would have been more valuable if Mr. Schieldrop himself had made some experiments with models on his plan and had given us the results obtained. The main conclusion I have come to is that Series I. appears to be hardly worth undertaking, but that Series II. is certainly novel and interesting, and might give us some valuable information. The difficulty of making the models is very evident, seeing that they are composed, not only of different kinds of wood, but also of gun-metal and steel castings with a rubber jacket stretched over all and a double thickness of wood sheathing outside that, all of which would have to be very, very carefully adjusted. I have some knowledge of the difficulties of making these scientific experiments, where corrections have to be made for all manner of small differences which may affect the result, and it is

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astonishing what work it leads to. The essential part—I might say the original part—of the paper is undoubtedly that which describes in detail the models themselves, and I think our thanks are due to Mr. Schieldrop for bringing it to our notice.

Mr. J. Macfarlane Gray (Member of Council): Gentlemen, having been partly responsible for the curtailment of the reading of the paper, I desire to say that I have, however, a high appreciation of its value. It starts from the fundamental idea, which we all recognise to be true, but seldom attempt to fully think out, that in any medium, in water, as also in the ether in which everything is moving, there can be no continued movement of a body in one direction but there must be at the same time an equal and opposite volume-momentum of the medium across the same transverse plane; otherwise the medium, whether water or ether, would gather up ahead of the moving body. It is, however, the algebraic sum of the volume-momenta in the transverse plane which must by their opposite equality mutually cancel. The opposite volume-momentum may by itself greatly exceed—it can never be less than—the onward volume-momentum across the transverse plane. The equality is maintained by the opposite volume-momentum being associated with superfluous onward momentum of volume in the eddies produced by imperfection of cleavage of the water, and by what is called skin friction. To get, by actual experiment, how these additions are introduced, by measuring the forces separately acting over the elemental surfaces of a hull, as the author proposes to do, would no doubt advance by a great step our knowledge of the nature of hull resistance. I think that an hour or two spent in conversation with Mr. R. E. Froude would help the author more than the complete reading of the paper before us now. We must all be struck with the remarkably intelligent way in which Mr. Schieldrop has expressed his views, so that, although not able to follow connectedly every statement, it has yet been a pleasure to listen to him. I am sure we are all very much indebted to the author for his carefully prepared paper on a subject of great interest, and we appreciate highly the compliment he has paid to this Institution in bringing it before us. Each of us, I am sure, sympathises with Mr. Schieldrop in his desire to see these experiments carried out, and, no doubt, the object he had in view in preparing the paper and coming so far to read it to us will be fulfilled by his having had the benefit of the opinions of the gentlemen who have spoken on it, and perhaps of Mr. Froude also.

The following written remarks were contributed by Mr. R. E. Froude, F.R.S. (Associate Member of Council): The proposal of this paper seems to me to be in its motive inconsistent with a correct appreciation of the existing theoretical knowledge concerning the resistance of ships. Starting with the fundamental proposition that the statical fluid pressures on the entire wetted surface must have a purely vertical resultant, it follows, of course, that resistance to movement through fluid can only arise from (1) quasi-frictional forces acting along the surface, or (2) local modifications of the fluid pressures from those of the purely statical system, such as to yield a horizontal resultant; or both in combination. Now, if we knew no more than this, if our general knowledge of hydro-dynamics gave us no clue to the character and laws of the fluid actions which produce these effects, then, indeed, a diagnosis by measurement of the forces and moments acting on the different portions of bodies of systematically varied shapes—by way of survey, so to speak, of the forces and modifications of pressure in question—might be the only likely means of obtaining such a clue. Whether, even on this supposition, the mode of investigation here proposed would be really fruitful is a separate question, and one on which I do not wish to be understood as expressing any opinion. Considering that, in ordinary shipshape forms, the resistance (over and above that of skin friction) is, in reality, only a small balance between large opposite forces due to the inertia of the fluid, it certainly seems

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doubtful whether the proposed apparatus, ingenious and well-considered as it is in many respects, would afford sufficiently accurate measurements; while the cost of construction and labour of analysis involved in the trial of any great variety of forms would be almost prohibitive. But, in reality, we have advanced far beyond the stage of investigation here supposed. It may be urged, I admit, that our computation of the skin-friction element of resistance, in actual vessels, is probably inexact as to absolute amount; that our knowledge of the amount of the wave-making resistance is empirical and very indefinite; and that we know almost nothing of the *rationale* of the remaining term in the resistance, due to imperfection of the stream-line flow (ordinarily described as "eddy-making"), or whether, or not, it has any importance in ships of ordinarily fine lines. Nevertheless, we do know for certain that, in ordinary shipshape forms, skin-friction and wave-making together account for the great bulk of the resistance; and that wave-making is not only a real and important cause of resistance, but is responsible for those peculiarities in the variation of ship resistance with variations of speed, to which appertain the chief difficulties in estimating the resistance of a novel design. So far as concerns ship resistance, at any rate, it is the wave-making which needs investigation. And we are sufficiently acquainted with the nature of this kind of resistance to know that it cannot be instructively investigated by determining the forces acting on the separate component parts of the moving body.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): If no other gentleman has any remarks to offer, perhaps I may be permitted to say a word or two before asking Mr. Schieldrop to add any remarks which he may wish before the discussion closes. I have read this paper, and have a fairly complete idea of what Mr. Schieldrop intends to discover, and the means by which he proposes to make that discovery. If gentlemen will turn to the illustration at the end of this paper, they will get a clearer view than from anything which has yet been said of the amount of thought which has been been bestowed by Mr. Schieldrop upon the construction of the models and the recording apparatus. I quite endorse what Mr. Morrish has said. I do not think that these experiments are necessary for the purpose of verification of the stream-line theory. If it were possible to determine experimentally the normal pressures on sections of these models by any recording apparatus as the water flows past the model, or when the model is drawn through the water, it would be a very interesting thing indeed. But, to my mind, there is a fundamental difficulty about it, and it is of this nature. If a model, no matter how beautifully constructed it may be, is made in sections with a view to the external fluid pressures upon it being recorded internally, it appears to me there would be a very considerable difficulty in maintaining an absolute continuity in form of the model. This continuity is essential to the determination of its resistance as a solid body. Taking the model on the table (that of a submarine boat), we will suppose that it represents Mr. Schieldrop's model. He proposes to take a section of that model and to determine the resultant pressures upon it in certain directions. To do this, displacements of the section in question would take place equivalent to movement of a portion of the shell. These movements may be very small, but they would disturb the absolute continuity of surface which would exist in a rigid body. If Mr. Schieldrop can conquer that difficulty, and can preserve continuity of surface in the model while recording pressures on the sections of the model, then he will have achieved a great triumph. I would beg Mr. Schieldrop to believe that his paper, prepared with so much care and ability, will be carefully studied by the members of this Institution, and it is not likely to die or to fail to attract interest because to-day we are not in a position to discuss it. He comes to us, after perhaps years of study, and the deepest consideration, and to his mind the subject is no doubt clear and simple. To us who have to take this

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paper *de novo*, and to many who have not had an opportunity of reading it, this is a matter requiring careful study. Mr. Schieldrop may depend upon it that the paper will receive that study, and in Mr. Froude's absence I may add that by nobody will it be studied with greater interest than by Mr. Froude. I do not endorse Mr. Macfarlane Gray's opinion that Mr. Froude, or anybody else, apart from such preliminary study, would be in a position to usefully discuss the methods proposed. They are clearly expressed; it is impossible to express them more clearly than Mr. Schieldrop has done. His intentions and methods are here set forth in a form that the members of this Institution can understand and consider, and I beg you, Mr. Schieldrop, on behalf of the Institution, to accept our united thanks for contributing this paper, and I give you the assurance that it will be carefully studied.

Mr. B. Schieldrop: Before attempting to meet the points which have been raised regarding my paper, I must ask your permission to make a personal remark. Sir William White's Manual of Naval Architecture is the book which has been most frequently in my hands during late years; and, for the first time, to stand face to face with its author on this occasion—which will be so memorable to me—impresses me so keenly that I cannot help giving expression to it. With regard to Mr. Morrish's remarks, it is not the purpose of the proposed experiments to establish or to verify the stream-line theory. My proposition is—independently of existing theories or of any previously obtained information—to ascertain experimentally the magnitude and character of the dynamic forces which each integral part of the surface of a solid contributes to the total resistance. The apparatus which it is proposed to use will be applicable to floating bodies as well as to those which are entirely submerged, and the bodies may be given any desirable form. When it is proposed at the outset to give the models strictly mathematical lines, then this is merely to facilitate an easy, clear, and exact description of their forms; and also for the sake of convenience in connecting causes, viz., forms of solids, with effects, viz., resistances. The proper start will be with models entirely submerged, because this is the least complex case, there being then no wave-making resistance; and it is natural and correct to attack the problem at its simplest end. It has been pointed out that the experiments will be very expensive, and demand much care. This is certainly so. But the extent to which it will be justifiable to expend care, time, and money in obtaining certain results will chiefly depend upon the valuation placed upon such results. That absolute impossibilities will be in the way, I do not believe. I do not doubt, for instance, that a careful investigation of the details will show that the forces may be measured and still maintain the necessary continuity of form of models. Mr. Froude's (written) remarks I must be permitted to discuss more fully. Let us suppose that the surface of any ship-shaped body be divided up into say, fifteen parts, by two transverse planes and five longitudinal (sheer) planes; and suppose, further, that we were able, at any time, to secure accurate knowledge of the resultant of the forces acting on each of these fifteen parts, in a state of rest the sum of the components of these resultants in any horizontal direction would be 0. But, when the body is set in motion, this sum of components, parallel to the line of motion, would be equal to the total resistance of the body. These records would show:—(1) How each of the fifteen parts of the body contribute to the total resistance; (2) The shifting position of the resultant, with reference to the centre of gravity of its part, would indicate the distribution of the retarding forces over this part; (3) The direction and magnitude of the resultant would show to what extent the forces parallel to the surface (frictional resistance) and the normal forces have been active in producing the changes; and (4) a comparative examination of all these fifteen resultants would bring out the interdependence of the dynamic forces, and give a very eloquent representation of how that equilibrium of forces, which prevails when the body is at rest, is disturbed by the motion. Further, if the body is submerged below the surface of

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the water, so as to avoid surface disturbances within certain speed limits, then—abiding by Mr. Froude's deductions as to the character of the forces which can possibly contribute to resistance—we would have only two kinds of resistances in this case, and each of these would have an emphatically different influence upon the resultants. A possible resistance due to an imperfect stream-line flow would manifest itself by a change in the normal components of the resultants. And a scrutiny of the records would disclose, not only the presence of a resistance of this character, but also what features of the body are conducive to the creation of such forces, as well as their ratio of increase with speed, and how they are distributed over the surface. By comparing the latter results with those obtained when the body is simply immersed (floating), we would have two parallel sets of records; one with, and the other without the influence of surface disturbances; and, as this latter influence—the wave-making resistance—has its origin in phenomena so widely different in character from those creating the other groups of forces, it will certainly have some peculiar characteristics of its own, as to distribution, ratio of increase with speed, or the like; which peculiarities will be brought out by a study of the records. I am very well aware that the method of investigation here proposed is very different from those which have been generally adopted in attempting to bring light upon this subject. But Mr. Froude's objection:—"That the paper in its motive is inconsistent with a correct appreciation of the existing theoretical knowledge concerning the resistance of ships," I think is met by the consideration that, with the facts in our possession, which it is here the intention of securing, we would, to a great extent, be able to settle the very points which Mr. Froude states are now in the dark, viz.:—"That our computation of the skin-friction element of resistance in actual vessels is probably inexact as to absolute amount; that our knowledge of the amount of the wave-making resistance is empirical and very indefinite; and that we know almost nothing of the *rationale* of the remaining term in the resistance, due to imperfection of the stream-line flow (ordinarily described as 'eddy-making'), or whether, or not, it has any importance in ships of ordinarily fine lines." Moreover, it seems to me that the following words of Mr. D. W. Taylor give my motive in proposing this line of investigation very material support:—"Doubtless the day will come when the naval architect, given the lines and speed of a ship, will be able to calculate the pressure and velocity of the water at any point of the immersed surface. That day is not yet." And with this information in our possession, it seems to me we would have found a direct and practical way of deciding how those features of a ship which the designer has it in his power to choose, or to alter, will influence the resistance. Mr. Froude's objections to the methods of securing this information I shall not attempt to meet, because they are of an entirely general nature. I shall certainly be very pleased to discuss any specific point of the proposed method or apparatus with him. I beg to assure Mr. Froude, however, that I feel very much indebted to him for his candid and straightforward criticism of my paper. Permit me to thank you for your very considerate attention, and also to thank the Chairman, Sir William White, for his very kind remarks.

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REMINISCENCES OF EARLY MARINE STEAM ENGINE CONSTRUCTION AND STEAM NAVIGATION IN THE UNITED STATES OF AMERICA FROM 1807 TO 1850.

By Charles H. Haswell, Esq., Member.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 31, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

Marine Steam Engines of the primitive construction, and down to 1822, were of the vertical crosshead type, connected with sliding clutches directly to the water-wheel shafts, and also geared to a shaft with a fly-wheel at each end of it; the object of the connection was that of enabling the water-wheels to be disconnected and the engine operated independently and solely, to feed the boiler and work the bilge pump when the vessel was at a pier or anchored, as independent steam, feed, bilge, and fire pumps were then unknown. The steam and exhaust valves, if puppet, were operated by the hand gear of Beighton; when otherwise, the long slide valve was used.

This type of engine, with the crosshead, connecting rods, cranks, and shafts of cast iron, the key, crank and pin holes cored and cast in, was wholly used until about 1822, when the vertical overhead beam was introduced, and when the horizontal or inclined engine was introduced, the short slide valve was resorted to, except in the Southern and Western waters, where the lever puppet, operated by a cam, was wholly used.

The Boilers, with the exception of the very first few, which were plain cylindrical, set in masonry, were of copper plates of the design termed "D. and Kidney Flue," having but one furnace full width of inner space of front, the flame and gases of combustion leading through a flue of about two-thirds width of furnace into a back connection, and from thence into a return flue, which, from the outlines of its transverse section, was termed a "kidney flue," and from thence to a short vertical flue at the back of the furnace, and then extending up to the shell of the boiler, in a short shoulder of which, the base of the smoke pipe was set. The cause of this convexity to the inner side of the main flue, and the indentation given to the inner side of the other, was that the curved surfaces rendered socket bolts less necessary, with the limited steam pressure of 15 lbs. or less per square inch.

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On Southern and Western waters, where non-condensing engines only were resorted to in consequence of the waters of the rivers being too turbid for the continuous operation of a condenser, wrought iron cylindrical boilers alone were used and the character of the iron was such that the plates were cold riveted; generally internally fired, in some cases externally, and it was not until about 1820 that marine boilers were constructed of iron in Eastern waters.

Boiler Plates.—These were punched manually by the aid of a long wooden lever, on which four men exerted their force, and as the location for the punch was directed only by the eye of the operator, the spaces were frequently irregular, involving pinning, in order to bring the holes as nearly opposite as practicable, and hence the plates were frequently strained and the rivets set at an inclination; all of the latter were hand made, but in the East were driven hot.

Blow Offs.—These were not attached to boilers until steam navigation was well advanced. The exact period is not now ascertainable, probably about 1822. The boilers of steamboats on the bay and river routes, with the low pressure, and the consequent low temperature of steam with which they were operated, did not involve the necessity of the frequent blowing off of saturated water from their boilers, and the water was allowed to run out of them at the end of each passage, and then refilled with fresh water. In consequence of this neglect of blowing off, and the imperfect manner in which the plates of a boiler were riveted, a boiler at the end of a trip in wholly, or even partially salt water, would be loaded in its seams and joints with incrustations and stalactites of salt, to an extent that involved their being hammered and scraped off at the termination of the route. Felting of a boiler was unknown.

Cranks and Crank Pin.—The shaft holes of cranks were octagonal, and the latter were secured to the shaft with flat keys, the interspaces fitted with a cement of iron borings and sal ammoniac; and as the distance between the centres of the crank, from the varying shrinking of the metal and the casual settling of the cores, would differ from that of the exact required length of half stroke of the piston, the pin was forged with two longitudinal centres, one for the hub and the other for the eye of the crank, and when the pin was fitted and seated, it was held in position by a key in its end, which protruded beyond the eye of the crank.

Finishing.—So deficient were the facilities of lathes, planers, slotters, and drills, that "black work" of engines, as it was termed, was the prevailing finish. The connecting rod of a large vertical beam engine in the *Victory* was wholly finished in the smith's shop, its body after forging being dressed by swageing, the key holes drifted, and the ends and straps dressed with a flatter on an anvil and a horse file.

Cylinder Piston Packing.—This consisted of hemp gaskets, and, if the safety valve of the boiler was not raised during the initial raising of steam, the steam around the

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chimney flue would become so dry, as to char the wood blocking between the ribs of the piston, and also the piston packing; hence lead pipes, through which the gaskets were drawn, were resorted to.

Counters, Indicators, Salinometers, Brine Pumps, Steam and Vacuum Gauges, Metallic Packing, Whistles, and Oil Cups, other than the one in the cylinder head, by which the piston was lubricated on its exhaust side, were unknown.

Cut-offs.—These were operated by a cam on the water-wheel shaft; hence, upon the closing of the cut-off valve, all the steam in the pipe between the valve and in the side pipe up to the steam valve, was added to that expended without any effect that compensated for its flow, and, as a result, it was sought to save this expense, and Robert L. Stevens, of Hoboken, N.J., designed and successfully introduced the cutting off of the steam directly by the steam valve.

Compound or Woolf Engine.—In about 1824 James P. Allaire constructed the steamboat *Henry Eckford* with a vertical cross-head compound engine, the centre shafts geared to the water-wheel shafts; but, in the absence of a receiver the mutual operations of the cylinders were only at the extreme of the opposite strokes of their pistons. Soon after, and up to 1828, he constructed five other boats, namely, the *Sun*, *Commerce*, *Swiftsure*, and *Pilot Boy*, with like engines, and the *Post Boy* with an overhead beam engine, the cylinders being set at its opposite ends; but, as this type of compound engine operated at the moderate pressure of but 25 lbs. per square inch, it did not attain such an effect as to justify the increased cost and weight of two cylinders and their connection, and its further construction was abandoned.

Steam Chimney.—In 1827, James P. Allaire, of New York, invented the steam chimney; the original design being that of two cylinders of boiler plate, one within the other, connected and closed at both ends, the inter-space being about 5 in. in width, with a vertical diaphragm, connected near its upper end to the outer shell above where steam was admitted from the boiler, through two or more connecting pipes, which served also as fastenings and to hold the chimney in position. This diaphragm led down to within a few inches of the bottom of the chimney, and the steam was inducted down and under it, then up and around the inner cylinder, and from thence to the steam pipe opening in the top; thus the steam deposited its contained water in the chimney, to be vaporised by the heat at the base, and received also heat from that ascending the chimney, hence a material economy of fuel was attained with the advantage of obtaining dry steam. Boilers at this period did not foam (prime); the great proportionate volume of water, its area at the water-line, and the moderate heat in the furnace from wood, with but a natural draught, precluded it.

In 1828, the engine of a large steamboat, the *Chief Justice Marshall*, on the route from New York to Albany, broke down by the breaking of the head of her piston rod at

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its insertion into the cross-head socket; the cross-head, both connecting rods, and a centre crank were broken, and in four days new castings from the builder's patterns were made, the piston rod repaired, all fitted, and the engine ready for operation.*

In this connection it is to be considered that neither the eye of the crank was reamed nor the key-holes of the rods slotted; they, the crank eye, and the ends of the rods, were submitted only to the operation of a coarse file.

In the attachments to engines and boilers the steam gauges were constructed in the smith's shop, and consisted of an iron tube half an inch in diameter and 4 ft. in length, bent, with one of its legs 15 in. in the clear in length, and in the other the balance of its length was filled with mercury, on which was placed a light pine rod, the rise and fall of which, shown on a tin plate divided and numbered in inches, designated the pressure of the steam in pounds per square inch.

Steam navigation, up to the latter part of 1829, was confined to Long Island Sound, the Southern and Western rivers, and Canadian lakes and rivers, with a single passage of a steamboat from New York to Philadelphia, the *Phœnix*, in 1807, and one on the route from Havanna to Matanzas, and one from Charleston to Savannah. In 1819 the auxiliary steamer *Savannah*, of 380 tons, steamed and sailed from Savannah to Liverpool, she being the first steamer to cross the Atlantic Ocean.

In 1825, Mowatt Bros., of New York, owners of the steamboat *Henry Eckford*, attached a loaded barge to her, and transported it from New York to Albany; this was the first essay of steam towing, and, although its insufficiency and impracticability were generally predicted, the enterprise proved to be a great and lasting success.*

In 1826 a fan blower was first introduced under the grates of the boilers in the steamboat *North America* of the Messrs. John C. & Robert L. Stevens.

In 1828-1829 the rivalry for speed between the steam-boats plying on the route from New York to Albany was so great that, in the design of the boats, their beam was disproportionate to the weight of the engine, boilers, and deckhouses above, and they proved unstable; in order to reduce this condition, large logs of light pine wood with sharp ends were firmly suspended under their after wheel-guards and depressed for half of their diameter below the water-line, and in operation they measurably improved the stability of the boat.

In 1830, the patent of the steam chimney of Mr. Allaire was invaded, and its operation simplified by making the double cylinder an integral part of the boiler, open at its lower end, and extending to such a height above the boiler as to give the necessary surface to superheat the steam, and the required height and volume of steam space measurably to arrest foaming, by admitting the subsidence of the water, physically borne with the steam in its flow to the steam-pipe.

* Witnessed by the writer.

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Gongs for the engine-room were unknown, and in many of the boats, when the pilot was in his house (if there was one) or on the deck over the engine-room, he would signal to the engineer by the strokes of a stick or cane upon the floor of the house or deck.

All boats of course carried bells, and by them all notices of departure and of arriving were made known, and all salutes between boats were given by their bells. To blow steam, as is now done by a whistle, was intended as and held to be a challenge or an insult.

Fuel, up to the year 1836, was wholly of pine wood, at which period some owners of steamboats commenced experimenting upon the practicability of using anthracite coal. A steamboat on her route of six or more hours, could not have the capacity in her fire-room to contain all the wood required, and was compelled to pile it upon her side houses; and such boats as were on a long route, as from New York to Providence, were compelled to invade their upper deck with wood, and upon leaving the city had somewhat the semblance of a floating woodyard.

In 1836, James P. Allaire commenced the running of a steamboat, the *David Brown*, a light-built river boat with deckhouses and promenade deck, from New York to Charleston and return, the enterprise being almost universally held to be utterly impracticable. It was successful, however, and soon afterwards he built two other and larger boats for the same route, and, from that period, coastwise steam navigation was held to be so practicable that various lines to other ports were established. The *David Brown* was fitted for this new service with planking under her water-wheel guards closely joined and caulked, extending from the inside of string piece to the light water-line, which shielded the guards from being forced up by a sea. This device, after several essays at a proper term, is now known as the sponson.* In some cases on coast routes, instead of a closed shield, open slatting was resorted to.

1837.—The first propeller steamer was introduced.

1838.—Phineas Bennett designed, patented, and introduced in the steamboat *Novelty*, plying on the Hudson River, a vertical cylindrical boiler in which a hermetically closed furnace was supplied with air by a pump, and all the gaseous products of combustion of the fuel were driven into the steam-room of the boiler; the object of this design was to increase the generation of steam and reduce the proportionate area of heating service.† The boiler after a short period of service was removed.

Soon afterwards he introduced the design into a vessel built to ply between New York and Liverpool, under the conditions with her builder that, if the design proved to

* This term was given, also, by the writer.

† Witnessed by the writer.

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be acceptably successful, he was to be paid for the entire plant of engines and boilers and his services, but if not successful he was to remove the entire plant, and at his own expense, without any remuneration whatever. The engines and boilers were completed and operated, but they were not paid for by the builder of the vessel, and the boilers were soon after removed and replaced with others. In consequence of the ashes borne into the valve chests and cylinders, and the evaporation of the oil of lubrication by the dry heat of the steam, the valves were rapidly worn, and the cylinder pistons shrieked to a degree that would have rendered the design very objectionable, even if it had been successful in other points.

Captain John Ericsson arrived in New York in this year, and in 1842 he designed and directed the construction of the engines and propeller for the United States auxiliary bark-rigged steamer *Princeton*.

1839.—Anthracite coal was introduced as fuel for steamboats, and, to aid its combustion when a high pressure of steam was required, a fan-blower, driven by a belt from the water-wheel shaft, was first resorted to, but soon afterwards a small independent engine was resorted to, connected by a belt to the blower.

Anthracite coal was soon afterwards first burned without auxiliary draught in the open furnace of a steam boiler.

1840.—Wrought-iron shafts were first made, the construction varying wholly from that of the present period. Thus, iron bars from 2·5 in. to 3 in. square and of the greatest attainable length were laid up with a square section, the abut ends breaking joints with the other bars; hence the solidity of a section of the mass was only subjected to any imperfection arising from their ends not being wholly welded, by the percentage of the section of one bar to the whole number; and of all the shafts made up to the period included in this paper but one was broken, and that in consequence of its being insufficient in diameter for the stress to which it was subjected, and this result was foretold .when the diameter of the shaft was reduced from that given in the specifications.

1842.—The first steam frigates for the United States were constructed.

1846.—Captain John Ericsson applied a surface condenser to the engine of a revenue cutter, and in 1848 Pierson designed an improvement which was further improved by Chief Engineer William Sewell of the Navy, and the perfected instrument is now in general if not in universal use.

1848.—The *Atlantic* and *Pacific* of the New York and Liverpool S.S. Company, "Collins Line," were constructed in this year, and in July, 1850, the *Atlantic* made the then quickest passage between New York and Liverpool, it having taken but ten days and fifteen hours. The *Arctic* and *Baltic* of the same line were launched.

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1850.—Horse Power.—It is wholly impracticable to obtain the consumption of fuel per indicated horse-power in early steam engineering, as engines were not fitted with counters or indicators and the wood was not weighed. In 1840, with auxiliary or blower draught, and in the absence of counters and indicators, it was computed by weighing the coal consumed, and held to be about 5 lbs., and the velocity of the river boats, from 8½ statute miles in 1816, increased to 19 miles.

DISCUSSION.

The following letter from Sir Frederick Bramwell, who was unable to be present, was read at the meeting:—

5, Great George Street, Westminster, S.W.,

Dear Mr. Holmes, *March* 31, 1898.

I am very sorry that I shall not be able to attend the meeting this evening to hear Mr. Haswell's paper on "Reminiscences of Early Marine Engine Construction and Steam Navigation in the United States of America, from 1807 to 1850."

Mr. George Tangye, of Soho, has very kindly lent me some original documents by Mr. Robert Fulton, which, although they are before the earliest date mentioned in the paper, I should have asked the Chairman to allow me to produce; but, as I cannot be present, I send them to you thinking that some of the members present may like to see them.

The first is dated from the Bridgewater Arms Hotel, Manchester, on November 4, 1794, and is from Mr. Robert Fulton to Messrs. Boulton & Watt, asking the price for a 3 or 4 H.P. engine, to be placed in a boat.

The next is a letter of August 6, 1803, from Mr. Fulton to Messrs. Boulton & Watt, accompanied by a drawing of that date (Plate XXVI*a*.), and a print of the time bill of the steamers *Rariton* and *Phœnix*, from Philadelphia to New York, fare price 4½ dollars.

The last paper is a letter of July 28, 1804, from Mr. Fulton to Messrs. Boulton & Watt, with sketch of the engine that he requires.

I enclose these papers, in case you can make any use of them, and must ask you not to let them go out of your custody, as they are only lent to me.

I should also have been glad to have been allowed to mention another matter in connection with somewhat early marine engine construction, namely, three years after the limiting date of Mr. Haswell's paper.

When I was in New York, in 1853, there was a steamer plying from New Jersey to New York the real name of which I forget, but the nickname I remember as that of the "Smoothing Iron."

I believe I have alluded to this steamer in meetings of the Naval Architects, but, even if so, I hope I may be allowed to repeat that the steamer had a flat bottom, and was provided for about two-thirds or three-fourths of its whole length, measured from the stern forward, with four or five

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very shallow strips (one can hardly call them keels) running longitudinally, and closed at their forward ends. Into each of the channels thus made there was injected air by an air pump, under a slight pressure, only just sufficient to overcome the "head" of water, and this air travelled along the channels and escaped at the stern. In order to keep down the species of ebullition, there was a projecting work at the stern which earned for the boat the name of the "Smoothing Iron."

The object of the inventor was to substitute air friction for water friction. I saw it at work, but I was never on board of it, and my recollection is that I was told that about the same result was got out for the total horse-power employed as would have been obtained if none of the power had been devoted to working the air pump, and if it had all been employed to the paddles of an ordinary water-skin-friction boat.

Believe me to be yours very truly,

FREDERICK BRAMWELL.

The following are the letters from Mr. Fulton to Messrs. Boulton & Watt referred to in Sir Frederick Bramwell's letter They are published by permission of Richard Tangye, Esq., without prejudice to his copyright. (The spelling of the originals is preserved) :—

MANCHESTER *November 4th* 1794.

GENTLEMEN,

I shall esteem it a favour to be informed of the expence of a steam engine with a rotative movement of the purchase of 3 or 4 horses, which is designed to be placed in a boat. You will be so good as to mention what sized boat it would ocupy, as I wish to have it in as little space as possible; and what you concive will be the expence when finiseed compleat in the boat; whether you have one ready of the dimentions specified, or how soon one might be finishd, with the weight of coals which it will consume in 12 hours and what quantity of purchase you allow to each horse. As I am anxious to apply some engines of the above dimentions as soon as possible, your emediate answer will much oblige your

Most obedient and very humble servant

Bridgewater Arms Manchester. ROBT. FULTON.

Messrs. BOULTON & WATT, Birmingham. PARIS *the 6th of August* 1803.

GENTLEMEN,

If there is not a law which prohibits the exportation of steam engines to the United States of America, or if you can get a permit to export parts of an engine, will you be so good as to make me a cylinder of a 24 horse-power double effect, the piston making a 4-ft. stroke; also the piston and piston-rod.

The valves and movements for opening and shutting them.

The air-pump piston and rod.

The condensor with its communications to the cylinder and air pump.

The bottom of the cylinder cast in form as in the drawing (Fig. 1, Plate XXVI*a*.), and the dispositions of the parts as near as possible as they stand in the drawing. The other parts can

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be made at New York, and as it will save the expence of transport, and they require a particular arrangement which must be done while I am present, I prefer having them done there. Therefore if it is permitted to export the above parts, you will confer on me a great obligation by favouring me with them, and placing me the next on your list —— when finished please to pack them in such a manner as not to receive injury and send them to the nearest port which I suppose is Liverpool to be shipped to New York to the address of Brockhurst Livingston, Esqre., the amount of the expences will be placed to your order in the hands of George Wm. Erving, American Consul, Nicholas-lane, Lombard-street No. 10, London. The situation for which this engine is designed and the machinery which is to be combined with it, will not admit of placing the condensor under the cylinders as usual, but I hope the communicating tube to the condensor will not render the condensation less perfect or injure the making of the engine.

Should you find a difficulty in getting a permit to export the parts above mentioned, I hope to be able to obtain it through our minister, Mr. Monroe. And as there is some difficulty in passing letters to and from Paris and Birmingham, which may loose much time, you will be so good as to furnish me the above parts as soon as possible without waiting to hear further from me.

Please to write as soon as possible under cover to Mr. Erving, as before mentioned. In which I beg you to answer the following questions:

What must be the size of the boiler for such an engine; how much space for the water and how much for the steam? What is the most improved method of making the boiler and economic mode of setting it? How many pounds of coal will such an engine require per hour, and what is the expence at Birmingham?

Can you inform me what is the difference in heating with coals or wood, as in most cases wood must be used in America; and must not the furnace be made different when wood is to be used?

What will be the consequence of condensing with water salt, as in places where the engine is to work the water is brackish?

What will be the interior and exterior diameter of the cylinder and its length, and what will be the velocity of the piston per second? This information will enable me to combine the other parts of the machinery.

When can the engine be finished, and how much will be the expence? Your favouring me with the execution of this order and answering the above questions will very much oblige your most obedient servant

ROBERT FULTON.

Rue Vaugirard No. 50 à Paris.

Can the position and arrangement of the cylinder condensor and air pump be adhered to as in the drawing without injuring the working of the engine?

Messrs. Boulton Watt and Co.

Gentlemen,

I like your mode of placing the air pump in the condensor, but as my movements confine me to 3 ft. in width, the condensing vat ought not to exceed that *width*, could not the condensor be made

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like a box, about 4 ft. long, 20 in. wide, and 2 ft. deep, as in this sketch (Fig. 2, Plate XXVI*a*.) If so, I shall be completely accomodated; if not, you must use your particular composition of the parts. I must beg of you, however, to fit me in this respect; if possible, perhaps a hole at A may be convenient for a man to pass his arm and draw any chips or dirt which might get into the or rather under the valve of the air pump, the hole to be covered with a plate. In a former letter I mentioned that the air pump will have a stroke of two feet. I see by your drawing you have it 16 inched diameter in the interior. I presume this width is calculated accordingly.

On tuesday I go out of town for 6 weeks or two months. I shall not trouble you farther about the combinations you will have the goodness to proceed immediately to the construction on the manner you deem best suited to my purpose.

I am with much respect

Yours

London the 28th of July 1804. R. FULTON.

Mr. B. MARTELL (Vice-President): My Lord and Gentlemen, I do not think one can discuss this paper, because there are no real facts on which discussion can take place. As it is of a historical character, and seeing the purpose for which Mr. Haswell—who told me about this when we met at the last meeting—has taken the trouble to write this paper, I think we should have it recorded in our Transactions, and that the Secretary should be authorised to express to him the thanks of this Institution for supplying us with this information.

Mr. J. MACFARLANE GRAY (Member of Council): I think there ought to be a statement added to this paper, because it may be looked at two hundred years after this. It seems to me to be the description of the Jubilee procession of last year from one side of the street, but there were other people on the other side of the street. Two hundred years after this (I do not know that it will affect us very much) they might like a true account of this procession of invention. We were as far forward in it in Europe as they were in America.

The SECRETARY (Mr. George Holmes): The title of the paper is: "Reminiscences of Early Marine Steam Engine Construction and Steam Navigation in the United States of America from 1807 to 1850."

Mr. MACFARLANE GRAY: If a sentence of my remarks were added to the paper it would put it on record that there might be two accounts of it. I would not dispute that account from the American side, but it did not all originate there, and we do not want it to appear two hundred years after this as if it did.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I feel certain, at any rate, that you desire Mr. Martell's motion to be carried, and that the thanks of the meeting be sent to our venerable friend.

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DESCRIPTION OF SOME EXPERIMENTS WITH A WATER-TUBE BOILER.

By A. F. Yarrow, Esq., Vice-President.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 31, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

In this paper, which I have the pleasure to submit to the meeting, I propose to describe some experiments made last year, by us, with one of our water-tube boilers. The boiler selected had a grate surface of 33 sq. ft. and a heating surface of 1,840 sq. ft., having tubes varying from 1¼ in. to 1 in. diameter.

Fig. 1, Plate XXVII., gives a general idea of the boiler, which no doubt is familiar to most of you. Numerous experiments were tried with a view to test the consumption of fuel at different rates of evaporation, and, to make comparison easy, the results are set out in the form of a curve, as shown on Fig. 2, Plate XXVII. The vertical distances represent the amount of water evaporated per lb. of Welsh coal and the horizontal distances the amount of water evaporated per square foot of heating surface.

As the draught is forced, and the evaporation more rapid, the extent to which the economy falls off is clearly seen. This mode of setting out boiler experiments renders comparison between different boilers and changes in the same boiler very apparent.

The various spots on the diagram represent different experiments, and the thick line A B shows the results obtained with the boiler as usually constructed. To the thick line is added a dotted line B C, showing further results at abnormal rates of evaporation. In these experiments the feed was passed into the boiler, mixing at once, as usual, with the water already in the boiler. After making a large number of trials with the ordinary method of feeding, we then partitioned off, as shown in Fig. 3, Plate XXVII., by diaphragms in the bottom pockets, three outer rows of tubes on each side, and we allowed the feed-water to pass in at the right-hand side of the diaphragm on the right-hand leg, and at the left-hand side of the diaphragm on the left-hand leg. The effect of this was to increase the evaporative efficiency, as indicated by curve D E. The observations upon which the curve D E is based were taken by an officer from the Controller's Department of the Admiralty.

The reason for the advantage gained a little reflection will show. Take, for example, a working pressure of 250 lbs. The corresponding temperature will be

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406° Fahr. Assuming that the heated gases coming in contact with the last three rows of tubes have a temperature of, say, 700°, there will be a difference of temperature between the heated gases and the tubes of 294° Fahr. Now, if those three rows of tubes are supplied direct from the feed pump with water, say, at a mean temperature of 200° Fahr., there will be a difference between the temperature of the water in those tubes and the gases coming in contact with them of 500° Fahr.; *i.e.*, in the latter case the difference of temperature will approach nearly twice what it was in the former case; and, as the greater the difference of temperature between the gases and the heating surface the greater the absorption of heat, the advisability of keeping as cold as possible those surfaces which are called upon to absorb the last remnant of heat from the gases is clearly evident. The outer rows of tubes thus act, as it were, as an economiser or feed-heater of a very simple character, forming part of the boiler proper, having the advantage that, instead of being in the uptake and depending for their supply of water solely on the feed pumps (which, in case of stoppage, might result in serious damage through the surfaces becoming over-heated), in the system described the tubes are dependent upon two means of supply, namely, from the feed pumps, or (in the case of the stoppage of the feed pumps) from the water in the upper chamber, which would flow down into these tubes.

This remarkable gain we desired to have confirmed, quite apart from our own observations, and in an altogether different manner from that in which our experiments had been tried. Professor Lambert and Mr. Haddon, of the Royal Naval College, kindly undertook to investigate this for us. In order to test the comparative merits of the two systems, namely, (1) feeding by the ordinary method, and (2) by passing the feed water through the three outside rows of tubes before mingling with the water in the boiler, the latter plan was adopted on the one side of the boiler, and the former plan, in which all the tubes took part in the general circulation, was carried out on the other side of the boiler, as shown in Fig. 4, Plate XXVIII. The object in view was to ascertain the temperature of the gases immediately before they came in contact with the heating surfaces, and their temperature immediately they left the heating surfaces, the difference indicating the amount of heat absorbed; and, clearly, if in one system more heat was absorbed than in another, other conditions remaining the same, that form of construction which led to the greatest absorption of heat would necessarily be the more economical.

I cannot do better than now give an extract from the report of Professor Lambert and Mr. Haddon:—

"Temperatures were measured by a Le Chatelier platinum and platinum-rhodium couple, combined with a 'dead-beat' galvanometer, carefully calibrated. The wires from the couple were covered with asbestos thread, and cased in a 4 ft. length of ½ in. gas pipe.

"In the first and second trials observations were taken while the furnace doors were

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closed, three inches away from the tubes, at nine different points on each face of each group of tubes, as indicated in Fig. 5, Plate XXVIII., holes having been cut in the boiler casing at the level of these points for the introduction of the tube containing the wires and couple.

"In the first experiment a rapid rate of combustion (52 lbs. per sq. ft. of grate) was maintained. In the second, a low rate of combustion (19 lbs. per sq. ft.), and in this trial special care was taken to read off at each point at, as nearly as possible, the same time after stoking, and always at that set of tubes further from the door (there were two fire doors) at which stoking had last taken place, in order to lessen the large irregularities due to periodical and frequent stoking. The means of the temperatures on the four faces are indicated in the accompanying Fig. 4.

"In order to further eliminate the irregularities due to the varying conditions of the fire, a third trial was undertaken, in which a very long series of observations was taken at about half-minute intervals, without reference to the times of stoking, so as more nearly to correspond to actual working conditions, the temperatures being read off simultaneously by two thermo-couples fixed opposite the centres of faces A and B, and afterwards a similar long series of obervations opposite the centres of C and D. In all, over 300 records were made. The means of the temperatures thus last obtained on the fire faces are higher than those of the first two trials, as all the records were taken at the middle of the faces where the previous experiments had shown there was greatest activity. The results are recorded on the Fig. 4, and in the table beneath it.

"*Funnel Temperatures.*—These were taken by the thermo-couple at the bottom of the funnel, 9 in. below the steam blast, while the doors were closed, and at different periods after stoking, and the means of several observations gave temperatures 662° Fahr., 433° Fahr., and 608° Fahr., in the first, second, and third trials respectively.

"*Analysis of Flue Gases.*—During the first experiment three samples were drawn from the bottom of the funnel by an aspirator, and submitted to quantitative analysis, with the following results:—

	Percentages, Volumes.			
	Carbonic Acid.	Oxygen.	Carbonic Oxide.	Nitrogen and Water Vapour.
Sample A. Doors closed. One minute after stoking	10·5	9·5	0	80
,, B. One door open. Sample taken during stoking and after ...	9·03	12	0	78·97
,, C. Doors closed. Immediately after stoking	14·33	5·53	0	80·14

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The absence of carbonic oxide in each case indicates that the combustion was perfect.

"Sample A showed that 54·8 per cent. of the total oxygen admitted had been utilised.

"Sample B, *with open door*, showed, of course, a less proportion of oxygen utilised, viz., 45·5 per cent.

"Sample C, taken with doors closed, and immediately after stoking, gave a higher proportion of oxygen utilised, or 73·1 per cent., apparently indicating, to a certain extent, a higher efficiency than when sample A was taken, after the doors had been closed for one minute."

General Remarks.

"The highest temperature recorded was 2,282° Fahr. in the first trial. The difference between the mean temperatures on the inner and outer faces of the tubes was in each case greater on the side in which the outer rows of tubes were only supplied with water direct from the feed pump, the difference in favour of this system being 89° in the experiment with rapid combustion; 45° Fahr. in the case of slow combustion, and 67° in the medium case." These results clearly point consistently to the advantage of the new feed system, and towards confirming the previous experiments as indicated by curves A B and D E, Fig. 2.

In connection with this subject, attention may be drawn to the fact that, whatever gain there may be by the system described in this paper, it will increase as the working pressures, and consequently the temperatures of the water rise. During these experiments the varying efficiencies of different systems of stoking were most apparent. The object, of course, is to secure complete combustion and entire absence of carbonic oxide in the flue gases, and to secure this with a minimum admission of air, the heating of any excess of air representing loss in economy. There are devices for continuously recording, in the case of stationary boilers, the specific gravity of the flue gases, which serve to indicate if there be present carbonic oxide or unconsumed air; and I am told, on the best authority, in works where such a device is in daily use and the stoking guided by it, a marked economy has been the result. I would submit that if a device of this kind could be designed so as to render it applicable for use on board ship it would serve as a guide to efficient stoking.

DISCUSSION.

Mr. C. H. Wingfield (Member): My Lord and Gentlemen, I must congratulate Mr. Yarrow on the great improvement on the previous performance of his boiler which he has got by adding a feed-heater. Of course, a feed-heater is a help to any boiler, but in this case it is easily applied, and makes a very slight alteration to the boiler. What I propose to speak about more particularly is the method of plotting the results of the boiler trials. Fig. 6, Plate XXIX. is a diagram which I have used

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for this purpose for a long time, and, as I pointed out last year,* it is essentially a straight-line diagram. As a proof of this I have plotted on it four trials made by Professor Kennedy with a Thornycroft boiler (which was not fitted with a feed-heater). These trials were conducted under Dr. Kennedy's own supervision by a large staff of assistants who were thoroughly trained in experimental work, and, therefore, I think, very great reliance is to be placed upon the results. This being so, the fact that the four large dots at the top of Fig. 6 lie so closely along the thick straight line may be taken as sufficient confirmation of the statement that the correct diagram is a straight-line one. Other trials made by Messrs. J. I. Thornycroft & Co. with other boilers justify the continuation of the straight line as far as shown. Turning now to Mr. Yarrow's Fig. 2, Plate XXVII., it will be seen that he has used for base and ordinates the same terms as I have done; he has, however, shown curved lines among his dots. In the absence of a rational basis, such as I am about to describe, the dotted line E D is about as good a curve as could be drawn among them, and the same might be said of the curve lower down. The moment it is known, however, that the lines should be straight, it is seen at once that the thin line in Fig. 6, passing as it does quite close to four out of Mr. Yarrow's five experiments in which a feed-heater was used (which are shown by the five crosses), fulfils more nearly than the dotted curve the condition of passing near the greatest number of points. In the same way the lower straight line on Fig. 6 represents at least as well as Mr. Yarrow's curve the average position of the dots, which I have transferred from Fig. 2, representing the trials with his usual form of boiler. In view of the importance of having a clear notion of the probable direction and form of curve to be expected in a given diagram I have always made a practice, where possible, before laying one down, of so arranging the data that they may form a straight line when plotted; it being, as has been pointed out, so much easier in this case to determine its true position. Professor Rankine gave an approximate expression, on p. 293 of his "Steam Engine," for the probable efficiency of a boiler of given proportions, which was based on the fact that the rate of heat transfer through a boiler plate varies as the square of the difference of the temperatures of the water and furnace gases. Some seven or eight years ago I deduced from this the expression which I have placed above Fig. 6, viz.:—

$$W\,c = E\,B - (W\,h \times A),$$

where $W\,h$ = the pounds of water from and at 212° evaporated per hour per square foot of heating surface;

$W\,c$ = pounds of water from and at 212° evaporated per pound of coal;

E = the theoretical evaporation due to the heat developed in the perfect combustion of 1 lb. of coal;

B and A = constants, depending chiefly on the design of boiler and the supply of air to the fuel respectively.

It will be seen that this expression is the equation to a straight line, and it was in consequence of this that I first plotted boiler trials as per Fig. 6.† Though correct for the Thornycroft boiler, as far as shown, it is obvious that the equation cannot hold good much further, otherwise the sloping line would cut the base at a point where a large evaporation per square foot of heating surface corresponded to no evaporation at all per pound of coal. Such an absurd result shows that the line must curve upwards (instead of downwards, as in Fig. 2), so as to become more and more parallel

* *Engineering*, Vol. LXIII. p. 741.

† Since the above was reported, I have found on p. 300, Vol. XXXIII., *Engineering*, a diagram, by Mr. Wilson Hartnell, identical in all respects with my Fig. 6.

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to the base. In Fig. 2 the curve would strike the base even sooner than in Fig. 6, and I think this is another reason for preferring my own straight-line diagram as a standard one. In Fig. 7 I have shown another modified form of Rankine's original equation which I have found very useful. In using either of these expressions, it is necessary to know the values of A and B, and, as Rankine did not show how to obtain them, I would point out that, the value of E B being measured direct from Fig. 6, it is easy to obtain B by dividing E B by E. The slope of the straight line gives A, hence the "dip" at the tenth division divided by 10 is the value of this constant. Perhaps Fig. 7, Plate XXIX., is better for determining the value of A and B. Here A is measured direct, and E B is measured, as indicated, by the slope of the line. Since these diagrams show that the relation of the heating surface to the coal and water consumed is the measure of its efficiency, it will be seen (1) that the ratio of heating surface to grate is immaterial, provided the coal is well burnt; (2) that "forcing" a boiler does not consist in working the grate hard, but in a high rate of combustion of coal per square foot of *heating surface* rather than of grate area; (3) that to limit air pressure as is done in some quarters is a mistake, since a large grate and low air pressure may result in as hard work for the heating surface as a smaller grate burning the same amount of coal would cause. There are, indeed, reasons for believing that, if a boiler is properly designed to suit the conditions, a high air pressure may be favourable to greater economy, and would involve even less forcing, in the sense of roasting the tubes, than at present. I quite agree with Mr. Yarrow about the desirability of having an instrument which is portable and handy for measuring the amount of carbonic acid in the funnel gas. Professor Unwin, in his Forrest lecture,* called attention to this, and exhibited a Dasymeter (I think it is called), and since then I have seen designs for others, and, as I know many inventors are at work in this direction, I hope we may before long get a thoroughly reliable instrument. I think that is all I have to mention, except to thank Mr. Yarrow for this very interesting paper.

Sir John Durston, K.C.B., R.N. (Vice-President): My Lord and Gentlemen, I should also like to add my congratulations to those of Mr. Wingfield to Mr. Yarrow for his very interesting paper, and the willingness with which he gives us any information he obtains in his experimental work. I venture to give (Fig. 8, Plate XXIX.) a diagram showing the results of some evaporative trials with a boiler without an economiser in the *Sharpshooter* and the *Powerful*, represented by this curve C D, and a boiler fitted with an economiser, represented by the curve or, rather, the lines A B. The line C D is the result of about six trials in two ships, A to B is the result of four trials with the economiser. The base line, of course, on which the curves are constructed, is down below ten of these spots, but I have only had it drawn out to show, as Mr. Yarrow states, that as you increase the evaporation per square foot of heating surface so the evaporation per pound of fuel diminishes after certain points. This line A to B, from this angle between A and B, was the result of three trials, as I had to bring the line down in that way. The fourth trial was at the point B, but the curve begins to be nearer to the base line, as Mr. Wingfield indicated in one part of his remarks. I did that with a view of constructing curves which would fall as the evaporation per pound of coal fell. Of course, the same thing is shown in Mr. Yarrow's diagram, which he has exhibited to us to-night, but in the paper it was put in rather the reverse direction. Of course, if you understand the lines of origin, it is simple enough. As Mr. Macfarlane Gray told us yesterday, there is no doubt the greater efficiency of this method of introducing the feed into the boiler is due to the greater capacity of water for absorbing heat, and on the principle that the coldest water should meet the coldest gases. I do not quite see

* Minutes Proc. Inst. C.E., Vol. CXXII. page 163.

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where the double advantage, which Mr. Yarrow speaks of as pertaining to his arrangement, comes in, because if the feed pumps stop the boiler would very soon come to grief. Had Mr. Yarrow obtained the information we should have been pleased, and it would have been interesting to have had the result of this fitting tried on board that boat in driving the engine. It would have given us the combined result, and the combined effect, in driving the engines in that boat, and it would have eliminated any question as to the quality of steam produced. Of course, I am well aware the same thing applies to these lines which I have shown in this diagram. They were only obtained from the results of boilers tried on shore in the usual way, and blowing off steam through the safety valves. There is one other point, about the temperature recorded on the fire side of the tubes being over 2,000°. Mr. Yarrow no doubt can tell us if the records were taken so as to give us the exact temperature of the gases flowing, rather than that effected by radiation on the thermo-couples. Sight holes in the furnace would enable the stoker to see where he needs to put his coal in firing up, and we should welcome any device that would enable us to secure better results. I think, further, that it would be a good thing if we had some public engineering laboratory started in which boilers—say, at about 500 H.P.—could be tested driving a set of engines with Froude's dynamometer. Then we should get results covering the objects we seek, that is, to say, the economy in the total use of the steam both from the boiler and its work through the engines.

Mr. J. T. Milton (Member of Council): My Lord and Gentlemen, after the testimony we have had from Mr. Wingfield and Sir John, I think I need say no more about the obligation we are under to Mr. Yarrow for the way in which he always puts before us his most recent observations and experimental knowledge. In offering a few remarks, I would like to say, first of all, that Mr. Yarrow has not shown to us all the advantages which, to my mind, accrue from this method of putting the feed into the boiler. In the first place, he has given us only the advantage to be obtained in evaporative efficiency, but there is one very important further advantage which would come in, in the ordinary working of the boiler. If he adopts sufficient heating surface in his economiser to thoroughly heat the feed water, so as to raise it up to the temperature of the steam, all the impurities in the feed water will be deposited in those tubes, and that will mean that all the most efficient part of the heating surface of the boiler will be kept clean, the dirt being kept in the tubes farthest from the fire, where it will have least detrimental effect. Then, again, not only with regard to dirt, but also with regard to corrosive influences. If any corrosive influences are at work in the boiler, going in with the feed water, one would expect them to be most active where the feed water first strikes the boiler, and in that way we should expect to find the corrosive influences confined to the outer rows of tubes, instead of being spread all over the boiler, so that, when any corrosion does take place, the result will be, you will have to renew a few only of the tubes instead of all of them. Sir John Durston remarked as to what would happen if the feed pump stops. I do not think anything detrimental can happen if the feed pump stops, unless it is a complete breakdown of the feed engine. If the feed pump stops because you are slowing down your rate of evaporating water, and you do not want to put any more water in your boiler, your fire will naturally have the damper shut. Your attendants will take particular care that the fire is not very brisk, and the fans not running at full pressure; but in any case the little piece of the lower chamber shut off for the feed portion is exactly under the same condition as the whole of the ordinary Yarrow boiler is with the feed pump stopped. It has all the water in the boiler to evaporate before any mischief can take place. Mr. Yarrow showed us once before, in his experiments on circulation, that, when you have a number of tubes running down from the upper chamber to the bottom pocket, circulation takes place naturally in that

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little bit of a boiler, some tubes becoming downcasts, while others are upcasts, and so, in those circumstances, we shall find, in those tubes constituting the feed-heating part of the boiler, circulation will take place so long as the water-level in the boiler is above the upper ends of the tubes. Of course, if the feed pump stops after that, the boiler is bound to come to grief anyway. I should like to criticise, in a friendly way, some of the actual figures put forward by Mr. Yarrow. In the diagram and tables Sir John Durston has given us as the result of the tests of Belleville boilers, we must remember the difference between the curve A B and the curve C D (Fig. 8) is the result, not only of the economiser fitted in as an economiser, but it is the result of having an extra combustion chamber put in the boiler. A great portion of the gain in the case of the *Europa* is, I believe, due to the fact that you have the extra combustion chamber. The Belleville boiler is emphatically one requiring a combustion chamber, especially when it is working at high rates. The products of combustion go immediately from the fire into the spaces between the comparatively cold rows of tubes, and, if they are allowed to cool down below a certain temperature, no further combustion of the gases takes place unless they are re-ignited. That this is the case in these boilers is seen from Sir John's paper to us yesterday, in which he said that in the new combustion chamber they have air jets mixing with the furnace gases there. Where we find the curve A B rising above the curve C D we must attribute the difference between them largely to the combustion chamber. With regard to the effect of an additional combustion chamber in a somewhat similar type of boiler, so far as circulation of the furnace gas is concerned, there is the Babcock boiler. The Babcock marine boiler was at first made in the old-fashioned style, with one large mass of tubes immediately over the fire; but, in some of the more recent of these boilers, there is an attempt to provide an additional combustion chamber by leaving out certain horizontal rows of tubes, and I believe I am correct in saying that those boilers have been considerably more economical than the older ones without the combustion chambers. Sir John did not give the actual figures, but he pointed out that this lower line marked "10" (Fig. 8) is really ten big spaces from the base line. Bearing that in mind, we shall see that this distance between A B and C D represents a gain of something like 15 per cent. in economy by the adoption of the combination of the economiser and the combustion chamber.

Sir JOHN DURSTON: 15·22.

Mr. MILTON: Now, let us come to Mr. Yarrow's diagram (Fig. 2). In Mr. Yarrow's diagram I do not think we can hesitate in accepting the curve A B, especially towards the point B, because that is the result of a very large number of experiments, and when you are drawing a line to represent the mean of a large number of experiments, you remember that all experiments are liable to small errors of observation, and you can never be sure within a small amount that you have actually the accurate result. It has been said that Rankine thought he was right in calling his result an approximate one, if it was not within 100th of the result. I think in ordinary practical work, if we come within 1 per cent., we should think we were very near perfection. The curve D E is the result of five experiments, three of them at nearly the same rates of combustion as those round the point B. I think if I had drawn the curve D E to represent these experiments, I should not have drawn it quite so far from A B as it has been drawn. I should have given more weight to the two experiments which are close together than has been done; I mention that because, as Mr. Yarrow has drawn the lines, there is about 15 per cent. difference between the efficiency shown by E D and A B. I do not think that one can rely absolutely on those figures. We can check the experiments in another way. By means of the temperatures of the furnace gases Mr. Yarrow has given us the mean results of the very many observations he has taken. He points out that 67 degrees difference in

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favour of the fed side is the mean of 300 observations. It is rather singular that 67 degrees is the mean of the figures he has given altogether as the results of three trials, so that this figure 67 practically represents the mean of the whole of the experiments. If we take the mean of the figures which he has given us on page 117 dealing with the analysis of the furnace gases, we shall find out that the amount of air, on an average, being used in proportion to the coal burned is between 20 lbs. and 21 lbs. of air per lb. of coal. From the ordinary method, suggested by Rankine, for finding the temperature of combustion, taking these figures of the fall of temperature in passing through the boiler, and assuming that the fall of temperature is equivalent to the amount of heat being transferred, we shall find instead of 15 per cent. loss we get something less. I should like to say a few words with regard to Mr. Wingfield's diagram. Some four years ago I was dreaming over a certain method of firing boilers, and so on, and I found my late friend Mr. Blechynden had been working on the same lines as I had, and we compared notes one day at Barrow. He was good enough to give me the particulars of some experiments made on some of his water-tube boilers tabulated in the same way as these are tabulated—it was not a question of the economiser. But from his experiments, which were conducted very carefully, when plotted out in a similar diagram to Mr. Yarrow's, I found that, where there was an evaporation approaching 9 lbs. of water per square foot, his result gave nearly the same figures as Mr. Yarrow's, in his boiler, and at 6 lbs. they came still nearer Mr. Yarrow's; but, when they got down to 3 lbs., instead of getting a greater efficiency, he found it was very much less than it was at 6 lbs. The maximum efficiency of his boiler was reached when he was evaporating about 6 lbs. of water per square foot of grate. He was rather astonished at first, until he went into the matter, when he found that the reason of it was this: when the boiler was being worked at low rates the products of combustion, instead of being spread all over the whole mass of the heating surface, seemed to take the shortest way to the chimney, and left all the lower part of the boiler-tubes practically unacted upon. That shows that you must not go upon formulæ altogether as to what you can expect, because, by all formulæ you would naturally expect the lower the rate of evaporation the greater the efficiency. Practical considerations often come in and upset the results of formulæ. Before I leave I would make one suggestion to Sir John Durston. He has pointed out that part of the result with the "Belleville" boiler and economiser is due to having the coldest feed water in contact with the coldest funnel gases. I think if he were to put the feed water into the top of his economiser instead of into the bottom (a very simple arrangement could be devised for preventing the economiser being emptied in case the feed pump stops) he would get some slight increase of gain.

Mr. E. N. Henwood (Visitor): My Lord and Gentlemen, I notice Mr. Yarrow has made some remarks here on page 116 as to the large irregularities due to the periodical and frequent stoking. It appears to me it would be interesting to the members of the Institution just to have a few remarks placed on record as to the advantages which have accrued where a water-tube boiler was fired by oil fuel, and, with your permission, my Lord, I would just give a very brief outline of those experiments or tests. It was on a 106 H.P. boiler of the Babcock-Wilcox type driving electric light engines, and the test made, critically judged by the employees of the Electric Lighting Company and myself with my assistants, so that no inaccuracies could arise, was this:—A feed-water tank was arranged so that every drop of water that could be put into the boiler was measured. It was found that, although the steam drum of the boiler was not lagged and there were openings at each side of the steam drum causing a considerable loss of heat, the evaporation was 15¾ lbs. of water (as nearly as I remember at this instant) per pound of fuel used. The heat in the furnace was so intense and so excellent that even

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the Lowood Ganister fire-bricks, of which the combustion chamber was made, failed to withstand it, and were within a few hours reduced to a liquid. That necessitated the providing of a fire-brick which would stand the intense heat, and these experiments have resulted in the production of a fire-brick made of pure flint which will stand and not give way even under that very high temperature. The waste gases passing out from the damper door were gauged by a pyrometer and found to be 400° Fahr., as against 600° Fahr. when a corresponding boiler was fired by coal.

Mr. H. M. Rounthwaite (Member): My Lord and Gentlemen, Mr. Yarrow is so exceedingly complaisant to us on all occasions, and gives us so much valuable information, that I think it is quite clear there is no other course open to us but to "ask for more." I should like to ask him if he has any objection to giving his reason for putting the feed water in at the bottom and discharging it upwards, and whether it was only the mechanical difficulties of reversing the operation that caused him to arrange the boiler in that way. I think the mechanical difficulties are not great, and that the feed water could be put in at the top by means of something in the shape of an injector nozzle, which would induce a current of water in the upper drum, and cause it to descend the outer tubes. In the boiler, as shown in Fig. 1, Plate XXVII., without any feed-heater arrangement, the natural course of the circulation would be upwards in the inner tubes next to the furnace, and downwards in the outer tubes. By taking away these outer tubes and converting them into a feed heater, it appears to me that the number of tubes available for the natural circulation of the boiler is somewhat interfered with; that the inner tubes next to the fire will still be upcast, and those next to the water tubes will be downcast, and the circulation in the central tubes, between those two, sometimes up and sometimes down. Therefore, I would like to know whether Mr. Yarrow does not think the arrangement and action of the boiler could be improved by reversing the circulation, and causing it to descend in the outer tubes.

Mr. J. Macfarlane Gray (Member of Council): My Lord and Gentlemen, just one sentence. I would like to say, in reference to my remarks yesterday about the heating of feed water by steam, that, accepting the experiments on which I based my remarks then, it would follow that a still better result would be obtained if the feed in this case also were supplied at the temperature of the steam, and the increase of temperature were effected by steam, and not by transmission through metallic heating surface at all. Only the latent heat ought to be communicated through the heating surface. All the rest ought to be by steam upon the cold feed—the steam from the boiler, and probably Mr. Yarrow, without very much extra trouble, might make the experiment.

Mr. T. W. R. Hughes (Member): My Lord, I should like to ask Mr. Yarrow if he would expect any advantage economically from connecting, say, the outer row of tubes with the second row at the top, and the second with the third row at the bottom, and circulating the water through the three series. I say, economically, because I should not advocate such a complication, especially in torpedo boats, or war vessels, believing as I do, that we should sacrifice something of economy to simplicity.

Mr. A. Haddon (Visitor): My Lord and Gentlemen, I do not know that I can add much to what Mr. Yarrow has already told you, but there is one point with which, most probably, he is not acquainted, that is, that when Professor Lambert and myself made these experiments, we tested as to whether there would be any great difference if the junction, plain and simple, were exposed to the fire, or if it were screened. We found there was very little difference indeed. The junction itself was protected by a ¾ in. iron tube, half of which, where the junction was situated, was removed, so that

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we had the opportunity, in that way, of causing the junction to face the fire or the screen, and we found scarcely any difference at all. Naturally, after a few minutes the screen itself became practically raised to the same temperature as the gases, through the absorption of heat direct from the gas and also by radiation, and, therefore, from that we came to the conclusion that the screen was practically of little or no use, and there was practically the same result whether it was exposed to radiant heat or not. As regards the measurements of these temperatures, perhaps a few words would be of interest. With a given apparatus there is very little difficulty in ascertaining these temperatures, providing you spend sufficient time in determining a proper curve. The curve is everything. We are told that the best means of determining temperatures are two; that is to say, you can determine temperatures by the variation in the resistance of a wire of pure platinum, and these results could be plotted on a curve, the variation of resistance with the rise of temperature being known; but we do not know much about this method of determining temperatures above about 1,000° Centigrade. Messrs. Callender and Griffiths have made determinations by this method, but I am not aware that they have exceeded 1,000° Centigrade. The most approved method of measuring high temperatures nowadays is by means of a junction of pure platinum and 10 per cent. rhodium and platinum. With such a junction the galvanometer requires to be calibrated, and, in such a case as this, the wires themselves have to be carefully insulated, one from the other. That was one of our great difficulties in the first experiments. We surrounded the two wires by means of combustion tubing, which melts at a very high temperature, but at the end of the run we found the glass tubes were melted together, and, although the wires were still insulated, nevertheless, this method was unsatisfactory. The next experiment made was to insulate them by means of asbestos thread, and that gave us very satisfactory results. We selected such a number of points as to give us a satisfactory curve, and the materials we selected were diphenylamine, the boiling point of that body, the boiling point of sulphur, the melting point of lead, the melting point of common salt, and, finally, the melting point of platinum itself, and we found there was a very slight bend in this curve that we obtained, and in order to check the observations we repeated the experiments with other wires from the same firm, and we got very, very near a coincidence of the two. Therefore, with those results we were certain it would be very easy to determine the temperatures at any part of the furnace. It is necessary when determining such temperatures to use a dead-beat galvanometer. With an ordinary galvanometer of Lord Kelvin's type you would have considerable variations in the position of the spot of light, and it would be exceedingly difficult to get a mean reading; but with a dead-beat galvanometer these fluctuations are reduced to a tenth or twentieth of what they would otherwise be, and in that way a very good mean can be obtained for any practical temperature that has been taken. I do not know, my Lord, that I can add anything more to what has been already said.

Mr. JOHN WATT (Associate): My Lord, I merely rise to say that a few years ago I designed a water-tube boiler for the purpose of accounting for as much of the heat lost as possible. I not only designed it with a feed-water heater at the top, but I enveloped it with what I term a feed-water casing. The casing in one of Mr. Yarrow's boilers would be simply this. On each side of the boiler there would be a large tube lying horizontally and near to the bottom of the boiler, and from it, up to another similar top tube, a series of small bent tubes. These tubes are placed close together, as close as you can get them, and the feed-water enters at the bottom and comes out at the top and re-enters the boiler. This feed-water casing, besides taking the place of the ordinary boiler casing, fulfils two purposes; that is to say, first, it prevents the heat from getting to the coal bunkers which lie alongside, the tubes being so close together that only a thin sheet of wrought iron placed over the

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surface is sufficient to keep them quite cool; and, secondly, it utilises the waste heat after passing from the boiler, and, as you will see, in boilers using steam of say 250 lbs. pressure you have a temperature of steam, and of the water, too, in the boiler, equal to 400° Fahr. Now the products of combustion passing from the fire to the outside of the boiler must pass off at a good deal over 400° Fahr., to leave anything behind, and if there was no feed-water heating arrangement to absorb this the boiler must be a very wasteful one. We must take advantage of everything we can get hold of in the shape of feed-water heating, or in casing the boiler so as to take the least portion of heat from the gases.

Mr. A. F. YARROW (Vice-President): My Lord and Gentlemen, I quite agree with Mr. Wingfield that it would be very convenient if the curve indicated on the diagram could be made into a straight line, but Mr. Wingfield will be the first to agree that the line is beyond our control. We have to make the line to suit our spots. If the line were straight, there would be a time when we should get no evaporation at all. I do not therefore see how it is possible that it could be straight. I think the nature of the curve would be something like a letter S. It would go on curving in one direction up to a certain point, and then would go off in another direction and make an S bend of it, because it is quite impossible that there could be a time when there would be no evaporation by increased forcing of the fire. That is confirmed by what Mr. Milton has told us of Mr. Blechynden's experiments, showing a maximum efficiency at about a medium rate of evaporation. I quite agree with what Sir John Durston has said, that the experiments we made would be far more valuable had they been tried afloat; but, as we have not got as far as that, I was only able to give what we have. As regards the radiation on the pyrometer, Mr. Haddon has replied to that much better than I could. Mr. Milton has kindly pointed out another advantage in adopting the system described, viz., the deposit collects in the outer tubes which are least exposed to the fire, and therefore less likely to be damaged by the fire acting on surfaces covered by deposit. I am much obliged to Mr. Milton for pointing this out. We must all agree with Mr. Milton that the proper combustion of the gases is, under existing circumstances, more important than any extra heating surface. I do believe there is more to be gained under the present condition of things by watching that the combustion is satisfactorily carried out than by getting a lot of extra heating surface into the boilers. Mr. Milton suggests that the curve D C is rather too favourable. I quite agree with him, it is so for ordinary working conditions. I have only described certain experiments. As it will be seen, all the feed goes in at one side. It ought correctly, and in practice it would go in on both sides, and therefore we have got, as it were, an unfair advantage; but it equally proves that the plan is correct, and will result in a gain. Mr. Rounthwaite asked why we put the water in at the bottom and not at the top. In the first set of experiments it was put in at the top, but there were certain difficulties which prevented it working well when carried out in this manner. These difficulties might probably be got over. As to the water in the middle tube being in an unstable state, not knowing whether to go up or down, to this I cannot agree. Experiment has shown it is not so. It might appear at first sight that the water would be in an unstable state in the middle tubes; but once it is started, either up or down, it will go on continuously in whichever direction it takes at the beginning. As we say, if you train up a child in the way it should go it will continue in the right way. So it is with water. When the current of water is started, either up or down, it continues in the direction it first took up; and it takes a great deal to alter it. Those who heard Mr. Macfarlane Gray's remarks yesterday must have been very much struck with them. That gentleman pointed out that, if you heat the feed-water by means of live steam, you gain. Although at first sight it may appear you are taking a shilling out of one pocket

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and putting it into another, that is not really the case. Mr. Macfarlane Gray, as he generally does, put it very pointedly. By heating the feed with live steam, so as to bring it up to the temperature of the water in the boiler, it enables that water, directly it comes in contact with the heating surface, to fly into steam, and that flying into steam produces a great deal of motion of the water against the surface of the heating surface. I think I am right in my interpretation, Mr. Gray?

Mr. Macfarlane Gray: Yes.

Mr. Yarrow: Well, if you have, as it were, comparatively still water against the heating surface it does not absorb the heat anything like as fast as it would do if it were in active motion. This is very easily illustrated. If you put your hand into very hot water and go on adding hotter water still, and keep your hand very still in the water, you can bear your hand in that water up to a very high temperature; but, if you begin moving your hand violently in that water, you will find you have to take it out very quickly. That is a very simple experiment, but it conclusively illustrates how much more rapidly the heat is conducted from the water to the hand when the surface of the water and the hand are moving continually past one another than when they are at rest. If you cause the water in the boiler to be moved rapidly in contact with the heating surfaces, it absorbs the heat much more readily than if you keep it comparatively still. I imagine that is really the point Mr. Macfarlane Gray drew attention to. Am I not right?

Mr. Macfarlane Gray: You are right.

Mr. Yarrow: I agree with Mr. Macfarlane Gray; and what Mr. Hughes has said is also to the point, that it is no reason, because you get a gain by heating by means of live steam, that you should throw away some other means of heating as well.

Mr. Macfarlane Gray: You render all that more efficient—you get more from the boiler, you get more evaporation. If you employ these outer tubes to do evaporation from the already heated water, you do more, and experiment would prove it, if you could work it out. You are making better use of those three tubes. You are not throwing away the three tubes—I propose to make better use of them.

Mr. Yarrow: Experiment perhaps will throw some light on this portion of the subject. I have nothing further to add, except to thank you, gentlemen, for listening to my paper.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): I am sure, gentlemen, you will unanimously accord a hearty vote of thanks to Mr. Yarrow for his very interesting paper.

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PNEUMATIC MACHINERY FOR LOADING AND DISCHARGING GRAIN CARGOES.

By Frederic Eliot Duckham, Esq., Associate.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, March 31, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

Our foreign grain trade holds a prominent position among the things which have changed during the past forty years. The increase of population and Free Trade have assisted in this, but the great advances which have been made in steam, in telegraphy, in shipping, and in machinery are undoubtedly foremost among the causes which have effected so great an evolution.

For, although the population of the United Kingdom increased from 28 millions in 1851 to 35 millions in 1891, enhancing the demand for food, and Legislature facilitated the supply of grain from abroad, the importation of such supplies would be very uncertain and costly were we yet to rely upon the old channels of correspondence and negotiation, coupled with the old methods of transport and of "working" the grain upon arrival.

Forty years ago 300 tons of grain were considered a good cargo, and if a skipper could manage to complete his voyage to and from a grain port of the Black Sea in five months he was thought to have done well.

These vessels, in addition to natural delays by wind and weather, were also detained at their ports of call while the merchants received samples, sold the cargoes, and sent orders for the ships to proceed to a port of discharge, where a few men would unload the grain by gin and winch during a very liberal allowance of lay days.

The change, which was slow at first, advanced with increasing rapidity, grain-carrying sailing vessels being replaced by screw steamers, some of which now carry as much as 4,000 tons per freight, and make the entire voyage to the Black Sea and back in eight weeks, including the time occupied in loading and discharging both the outward and the homeward cargoes. In addition to these, considerable development has taken place in the grain trade of the American continent, and some recent steamers for the Atlantic trade have a capacity of 12,000 tons.

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The tables appended show some changes which have taken place in the Mercantile Marine and in the amount and character of our grain importations. These may be epitomised thus :—

(*a*) The vessels belonging to the United Kingdom in 1850 had a total tonnage of 3½ millions of tons, of which the steamers represented 186,474 tons, or 4·8 per cent. ; in 1897 the total was just 9 million tons, of which 6⅗ million tons, or 71 per cent., was represented by steamers.

(*b*) The total tonnage engaged in foreign trade which entered and cleared in the United Kingdom ports in 1850 amounted to 14½ million tons, of which 2⅕ millions, or 15 per cent., were steamers; whereas in 1897 the total was 90 millions, of which 81 millions, or 90 per cent., were steamers.

(*c*) The value of imports and exports in 1850 was 192 millions sterling; in 1897 it was 745 millions sterling.

(*d*) During the ten years ending 1850 the imports of grain averaged 1,022,067 tons per annum, while for ten years ending 1890 it reached an annual average of 6,157,276 tons.

During 1896 the total quantity of corn and flour imported was 9,594,136 tons, possessing a declared value of £52,800,083.

To deal with such a large amount of trade, the old method of working by hand has been gradually replaced by the use of various machinery, such as the endless band, carrying a number of comparatively small buckets, travelling at a speed of about 100 ft. per minute in an enclosed trunk, and which has for some years been in use in America, in Liverpool, and elsewhere; but where the cargoes to be discharged are of a mixed character, *e.g.*, general goods and packages in the 'tween decks, and grain in bulk in the lower hold, it has been found more convenient to use hydraulic cranes with self-opening and closing grabs, or buckets filled by hand and self-discharging, or other contrivances with which to lift the grain, but which can at any time be exchanged for slings or hooks for the discharge of the ordinary merchandise.

In all these methods, however, it is only possible to reach such of the grain as is within the area of the hatch, the other portion, which may extend 100 ft. or more fore or aft, has to be trimmed to the hatch by manual labour or by the so-called steam shovel.

Grain is often brought home in bunkers and other confined spaces in which it is not practicable to employ either of these machines, and so the grain in these places has to be filled into sacks and unloaded by manual labour.

But when one has to deal with present-day vessels of 10,000 tons capacity, repre-

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senting a capital expenditure of £70,000 to £100,000, and debit of £70 for each day in dock, it is of very great importance to increase by every possible means the speed with which their cargoes can be loaded or unloaded.

In this direction the skill of the naval architect has been shown, and must still continue to be shown, in so designing the vessels that they may, not only be safe and otherwise satisfactory for navigation, but present the greatest facilities obtainable for the receipt and delivery of their cargoes.

It is also of importance that such improvements be made in the machinery employed that the greatest amount of work may be done in the shortest time and at the lowest cost with safety.

It was with such requirements in view that the author directed his attention to the employment of air for elevating and conveying bulk grain.

There was no originality in this idea, air under vacuum as well as under pressure had from time to time been tried in this country and abroad for this purpose; but several difficulties presented themselves, and prevented the successful operation of the machinery. Prominent among these were the difficulty of sucking or forcing grain in bulk through pipes, of getting the grain out of any vacuum chamber into which it had been drawn, and of separating the grain and its dust from the air which had conveyed it.

The author feels that he need not give in uninteresting detail the various steps by which these and other difficulties were overcome, but would at once refer to two types of pneumatic elevators which are now in successful operation.

One of these is employed for the discharge of sea-going vessels overside into barges, as in use at the Millwall Docks and the Albert Docks, London; Bremerhaven, Hamburg, &c. (see Plate XXX.). In these the machinery is afloat in a hull generally, say, 80 ft. by 24 ft. by 10 ft.; in each the machinery, under deck, consists of a compound engine connected direct with air-exhausting pumps capable of producing and maintaining a partial vacuum of 15 in. of mercury in a tank into which, say, 5,000 ft. of air, under atmospheric conditions, is being admitted per minute. The boilers are of the ordinary marine type, the engines are surface-condensing. On the deck of the craft one, or in some cases two or three towers are erected, each to support a vacuum tank, which acts as a grain receiver, and is, say, 10 ft. in diameter by 16 ft. high. This tank is coned at the bottom, and has connections for two or three pipes through which the grain is drawn with the current of air from the hold of the ship. An automatic air-lock is fitted, through which the grain discharges itself from the tank into the hopper of the weighing machine, and, after weighing, it flows into the barge in bulk; or, it may be sacked before delivery.

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The men required for the discharge of, say, 100 tons per hour are an engineer, a stoker, one man to each of the pipes, a leading hand, and three others for moving barges and general work. An elevator of 200 tons per hour capacity is just being designed; its crew will be no greater, except as to pipe man and an extra stoker.

The coal consumption is about three-fifths of a penny in London for every ton of grain discharged. This is heavy compared with the coal consumed by the ordinary bucket elevator, but as this pneumatic machine effects a direct saving of the cost of trimming the grain to the hatchway, the comparatively greater coal consumption sinks into insignificance. In fact, the whole operation of discharging is often less than what would have been the cost of the trimming alone.

The pneumatic machine has, moreover, other advantages; it is worked in all weathers; it not infrequently happens that the pneumatic grain elevators are the only ship-discharging appliances at work on a wet day on the Thames. In addition to this important saving of the ship's time, it is also to be noted that the suction pipes, being suspended from the elevator derrick, can be lowered into the ship's hatchway and the discharge commenced within a few minutes of the machine being brought alongside. There is none of the usual loss of grain in handling, as the cargoes are conveyed within closed conduits from the discharging ship into the receiving barge, and the grain is, moreover, improved by such intimate contact with the conveying air. This is specially so when the grain is heated and out of condition. The suction pipes, which are semi-flexible, can be taken by any tortuous route into the bunkers or other confined spaces, and the grain can be drawn out therefrom almost as readily as from the ship's hold. The pipes occupy so small a portion of the hatchways that other cargo is discharged by crane, &c., simultaneously. There is obviously an entire absence of the dangers to life and limb that are inseparable from the ordinary lifting machinery.

The elevator vessels are fitted with steam capstans to assist in moving themselves as well as the barges that come alongside for loading, and may be made self-propelling.

Another type of these machines is illustrated by that in use at Limerick (see Plate XXXI.). In this, the employment of a partial vacuum for elevating grain from the discharging vessel, just now described, is repeated; but, instead of the grain flowing in bulk into a barge alongside, it finds its way through a second air-lock into a chamber below the deck, into which air is forced at a pressure of from 6 to 8 lbs. per square inch. From this a pipe passes upwards, bends over the elevator's side, and is there connected by a piece of flexible hose with a pipe laid underground, up, into and along the roof of a warehouse. This pipe has outlets at convenient intervals, whence the grain is discharged into the desired bins. The Limerick machine is a screw steamer, and occasionally steams about twenty miles down the Shannon to lighten vessels of

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greater draught than could be accommodated at the docks. This elevator has a capacity of 300 or 400 tons unoccupied by machinery, and can carry this quantity of grain herself. The excess is put into barges which the elevator tows back to the dock. This machine has discharged, ex ship, into warehouse, 1,013 tons of maize in ten hours.

This same type of machine will probably be employed on an early day for loading vessels in America and elsewhere. The only change in the arrangement will be that the grain will be sucked out of canal barges and put into ocean-going ships instead of being discharged from ships and put into barges or warehouse.

In some cases the apparatus has been erected on shore, and is applicable for elevating and conveying any grain-like material, including small coal.

TABLE A.

SHOWING TOTAL NUMBER AND TONNAGE OF VESSELS REGISTERED AS BELONGING TO THE UNITED KINGDOM AT THE END OF EACH YEAR.

Year.	Sailing Ships.		Steamships.		Total.		
	No. of Ships.	Tons.	No. of Ships.	Tons.	No. of Ships.	Tons.	Av. ton. per ship.
1850	24,797	3,396,659	1,187	168,474	25,984	3,565,133	137
1860	25,663	4,204,360	2,000	454,327	27,663	4,658,687	165
1870	23,189	4,577,855	3,178	1,112,934	26,367	5,690,789	216
1880	19,938	3,851,045	5,247	2,723,468	25,185	6,574,513	261
1890	14,181	2,936,021	7,410	5,042,517	21,591	7,978,538	370
1897	11,911	2,589,570	8,590	6,363,511	20,501	8,953,081	437

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TABLE B.

TOTAL TONNAGE OF BRITISH AND FOREIGN VESSELS (SAILING OR STEAM) THAT ENTERED AND CLEARED WITH CARGOES AND BALLAST AT PORTS IN UNITED KINGDOM FROM AND TO FOREIGN COUNTRIES AND BRITISH POSSESSIONS.

	During the Years					
	1850.	1860.	1870.	1880.	1890.	1897.
Steamers :—						
British	1,802,955	4,186,620	13,341,058	30,076,037	49,023,775	61,372,033
Foreign	406,892	780,853	1,731,273	6,237,905	12,661,234	19,680,996
Total	2,209,847	4,967,473	15,072,331	37,213,942	61,685,009	81,053,029
Sailing Ships :—						
British	7,639,589	9,728,303	11,731,122	10,372,947	4,949,337	3,054,512
Foreign	4,655,628	9,993,516	9,836,729	11,149,174	7,649,523	6,091,322
Total	12,295,217	19,721,819	21,567,851	21,522,121	12,598,860	9,145,834
Steamers and Sailing Ships :—						
British	9,442,544	13,914,923	25,072,180	41,348,984	53,973,112	64,426,545
Foreign	5,062,520	10,774,369	11,568,002	17,387,079	20,310,757	25,772,318
Total	14,505,064	24,689,292	36,640,182	58,736,063	74,283,869	90,198,863

TABLE C.

VALUE OF TOTAL IMPORTS AND EXPORTS OF MERCHANDISE INTO AND FROM THE UNITED KINGDOM.

Years.	Imports. £	Exports. £	Total of Imports and Exports.
1850	100,469,000	92,214,000	192,683,000
1860	210,530,873	164,521,351	375,052,224
1870	303,257,493	244,080,577	547,388,070
1880	411,229,565	286,414,466	697,644,031
1890	420,691,997	328,252,118	748,944,115
1897	451,238,683	294,183,680	745,422,363

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DISCUSSION.

Mr. H. M. Rounthwaite (Member): My Lord, I should just like to congratulate the author on having successfully worked out the application of pneumatic power to the loading and unloading of grain cargoes. In 1878 I heard of a similar use of pneumatic power in America, and, having satisfied myself that the thing could be worked out, I entered into correspondence with a very eminent firm in the North of England, who had just previously completed a large plant on the bucket ladder principle, in the hope that they would take up my idea, but they did not think it feasible, and declined to do so; and, as I was at the time very fully engaged in ordinary marine construction, and had no time to give to other work, I was obliged to let the matter drop. But it is to the man who makes a thing an accomplished fact, not to the man who only thinks about it, that all honour is due, and I therefore congratulate Mr. Duckham most heartily on the successful issue of his labours.

Mr. B. Martell (Vice-President): My Lord and Gentlemen, I think we ought to express our thankfulness to Mr. Duckham for producing this paper here, and I say this more particularly, because some members have intimated that in their opinion it was scarcely a paper that was germane to the functions of this Institution. Now I think it was very much so. We must bear in mind that we not only have naval architects and engineers belonging to this Institution, but we have shipowners and merchants as well, as associates, who look forward to any information that can be given to them appertaining to ships where economy is one of the principal questions. Not only that, but likewise it is very important when such means as these are adopted for saving expense, and not only is credit due to the inventor of an apparatus of this kind, but it is also of very great assistance to shipowners and shipbuilders, in enabling them to design and arrange their ships so that an apparatus of this kind can be worked to the very best purpose. Therefore, I think the Institution is very much indebted to Mr. Duckham for reading this paper and explaining his patent, which appears to be well suited to the purpose for which it is intended.

Professor J. H. Biles (Member of Council): My Lord, I should like to say in continuation of what Mr. Martell has said, that I think, perhaps, we do not get enough papers in connection with subjects such as this, bearing upon appliances which have to be used in connection with ships. The inventors of appliances of this kind naturally take ships as they find them. They bring their improvements forward to the notice of those who have to use them, and they use them; but, if they were brought more frequently before this Institution, I think it would be quite probable that, in many cases, we would be able to suggest, not only modifications in their plans, but modifications in our own ships to make their inventions more applicable. Therefore, I think it is of great importance that a paper like this should be brought before this Institution.

Mr. J. Fell Redman (Member): My Lord and Gentlemen, it appears to me that Mr. Duckham and I have attacked this problem from opposite ends, as he uses a rather high vacuum—from 15 to 20 in. of mercury—and I had to measure my pressure by its velocity by means of an anemometer. By hanging an annular steam blower mouth downwards over a ship's side I found it practicable to induce a current of air up a 9 in. pipe at a velocity of about 8,000 ft. a minute, capable of carrying the heaviest kind of grain up lifts of fully 40 ft. With a portable hopper, 6 ft. by 3 ft. by 3 ft., resting on a low stout stool placed near the margin of a hatch, we could drop pipes straight down into the grain, and weigh out from the slide in the lower hopper quite conveniently, and truck sacks

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across the ship's deck, and deliver into a barge on the opposite side of vessel to that on which the steam blower was placed, thus avoiding any nuisance, or injury to grain by the steam. The upper hopper has a screen, arranged with gauze wire of various sizes, according to the grain to be worked. This can be as readily replaced with a fresh one as a magic lantern slide, and cleaned from time to time of the fluff from peas, or dust and rubbish found with all bulk grain. The first parcel worked was 300 tons of rye from a deep ship, and the outturn was within $\frac{3}{4}$ of 1 per cent. of bill of lading. By custom of the trade we are allowed 1 per cent., and the condition of the rye was greatly improved. A parcel of wheat from deep midship tanks of 500 tons was worked out for 6d. a ton, and, in due time, various lots of maize, peas, barley, and oats, amounting to about 4,000 tons, have been worked out by two of these machines, some being passed over an automatic weighing machine. Some idea of the portability of the apparatus may be formed when I state that one set of hoppers, pipes, and blower weighs just one ton, and can be carried in a cart; and as much as 27 tons an hour of wheat has been raised and delivered at the height of 40 ft.

Mr. F. E. Duckham (Associate): My Lord and Gentlemen, I personally feel much indebted to Mr. Martell and Professor Biles for the kind words in which they have spoken of my poor effort to-night. I do feel with them that there is an advantage to be gained by frequent communication between the inventor and the users of the invention, and my impression has been emphasised by a recent visit to America, where I certainly found that those who made machines and those who used machines were much more in touch with each other than in this country. I am speaking of workshop tools, and I think, even in connection with machinery for working on ships, it would be a good thing for those of us who are inventors, or makers of machinery, to have the privilege of being brought more in contact with those interested in the designing and building of ships. In reference to what Mr. Redman has said, he and I have been working on the same road, and have been in commuication more than once with reference to the conveyance of grain by the employment of air; but the injector to which he refers was tried by me in the earliest of my experiments. I found that, although it was very good for limited use, it was really no good at all in dealing with large quantities of grain. As I have said in the paper, the idea of conveying grain by means of air is not new, but I think I may claim, without any egotism—and I claim it, giving the credit, to a large extent, to my Directors, who have enabled me to carry out the experiments and bring the process into practical use—that the machines at Millwall Dock, and such as I have referred to in my paper, stand alone in the practical and economical use of air for grain conveying. I thank you very much indeed, my Lord and Gentlemen, for your kind reception of my paper.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): I beg to move that a hearty vote of thanks be accorded to Mr. Duckham for his paper.

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A GENERAL THEORY OF THE OSCILLATIONS OF A SHIP ON WAVES.

By Captain A. Kriloff, Professor at the Naval Academy at St. Petersburg; Associate.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, April 1, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

When, two years ago, I had the honour of reading a paper on the pitching of ships before this Institution, Professor Greenhill remarked, during the discussion, that it would be interesting to have diagrams of the rolling and pitching combined, and required thus the study which I mentioned in § 7 of my paper and in § 12 of the Appendix to it. Now I have the honour to present my investigations on this subject, *i.e.*, the general motion of a ship in a seaway.

The present paper is divided into two parts: the paper itself and the Appendix to it. The relation of these two can be briefly characterised thus: in the first part I state the results obtained, in the Appendix I really obtain them mathematically, and I explain the methods used.

It is almost impossible to begin a paper on the motion of ships on waves otherwise than by the name of the late Mr. W. Froude, whose classical work "On the Rolling of Ships" is the foundation-stone of every investigation of that subject. In this paper Mr. W. Froude states the question in the following most general form: "What is the cumulative result of the continuous action of a series of consecutive waves operating on a given ship?" Then he continues: "And in order to determine this it is necessary first to determine how each individual wave will act on her at each instant of time. What attitude does the ship at each instant seek to occupy in reference to the wave on which she floats, and what measures the force which urges her to take that attitude; or, to speak more strictly, what is the *position of momentary equilibrium* for a body floating on a wave, and what accelerating force towards that position will the body experience in terms of her momentary deviation from it?"

Considering, then, the simplest case of this most general question, Mr. Froude gives an approximate solution of it. This case is that of pure rolling under the restrictive hypothesis, that the dimensions of the ship are very small if compared with

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those of the wave, which itself is assumed to have a sinusoidal profile. Apologising for the last assumption, Mr. Froude, after having stated that the profile of a wave is nearly represented by trochoids, adds: "I have not been able to master the mathematical difficulties which this mode of treatment involves, though I am not without hope of succeeding in the attempt." The mathematical difficulty alluded to consisted in a want of such a solution of the hydrodynamical equations which would correspond to wave motion, and thus of a want of knowledge of the true dynamical structure of the wave. Although Gerstner's theory of trochoidal waves has been in existence since 1802, it was so completely forgotten that Rankine's genius was required to re-discover it again in 1863; but then Mr. Froude had other more important work to do than to establish subtle details of the theory of rolling, and thus the above-mentioned attempt has never been published. Nearly at the same time as Mr. W. Froude, M. E. Bertin in France began his series of investigations of the same subject, and, in order to take account of the dimensions of the ship, he calculated certain reduction co-efficients, the effect of which "is not to give an exact equation of the rolling, but to find such a wave slope as would produce on a ship of infinitely small dimensions the same effect as the given wave produces on the real ship under consideration." (Pollard et Dudebout, Théorie du Navire, t. iii. p. 227.) In 1871 M. B. de S. Venant, the celebrated elastician, treated the same question by a method differing from that of M. Bertin; he assumed the waves to be trochoidal; but, though his method applied well when the breadth of the ship is small in comparison with the length of the wave, it would require very long and tedious numerical calculations if we tried to apply it to treat the pitching of a ship, or her oscillations on an oblique course.

Mr. Froude, in his paper, has shown an approximate method of calculating the effective wave slope for this last case, but here the assumptions are of such an arbitrary character that it is impossible to judge of the degree of such an approximation; because, on establishing the fundamental equation of rolling, it was shown that the momentary position of equilibrium of the ship on a wave is, at every instant, that when her masts are normal to the wave surface; here this assumption is inapplicable—we cannot assign which normal is to be taken, the ship occupying the whole or even more of the wave length, at the same time the translational (heaving) motion of the ship is tacitly assumed to remain unaltered, and the pitching is left out of consideration.

The study of the heaving and pitching motion of a ship in a seaway is not only important in order to have a complete representation of her behaviour in a seaway, but its chief interest is to obtain the real positions taken by a ship on waves for the determination of the stresses which she has to experience. Sir Edward Reed, in his paper, was perfectly aware of this necessity, and, I believe, Sir Edward would not refuse me the permission of copying here the following lines of his paper, where the necessity of the above-mentioned study is expressed in the most eloquent and luminous

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manner, and which form, thus, the best introduction, I could desire, to my paper. "In attempting to approximate to the shearing and bending strains of *ships at sea*, we meet with a problem of great difficulty, and one which, in the present state of our knowledge, does not admit of complete or exact solution; in fact, it may be doubted whether the very varied and rapidly changing conditions of strain in ships, so situated, will ever be completely expressed in mathematical language, and brought within the range of accurate calculation in the same way as still-water strains have here been treated. It is, however, possible to distinguish the principal causes of straining in ships at sea, and in some cases to make approximations to what may be considered as their *limiting* values, as I shall show further on; but the dynamical aspect of the question, although the most important of all, is at present in some respects beyond our power, so far as its expression in *quantitative form* is concerned. That this is the case will be obvious on the most cursory glance at the conditions of a ship in a seaway. Neglecting, for the sake of simplicity, all considerations of rolling motion, and supposing the ship to lie directly bow on the waves, the passage of each wave along her length establishes, or tends to establish, a vertical motion in the ship as a whole (except under special conditions), and a rotary or pitching motion about some transverse axis, besides producing continual changes in the relative distribution of the weight and buoyancy all along the length. The ship's motion in pitching and ascending can be readily explained in general terms; but to express accurately the speed of that motion and the corresponding accelerating forces, as well as the straining effect of the percussive shocks that are nearly certain to be caused in it, is an undertaking I shall not attempt. Even if this could be done, it would still be necessary to consider the heaving or vertical motion of the ship and the rapidly varying nature of the wave supports, both of which are causes of important straining actions; and, in addition, with the effect of the passage of a succession of waves (far from being of uniform dimensions and periods) as well as with the influence of the ship's onward motion. Altogether, therefore, we have before us a most complex question, which can only be touched by some approximative method such as I am about to describe." After having described his well-known method, Sir Edward adds: "I give these figures merely as indications of what may be expected to happen in the changes of strain in ships at sea, and they probably fall much below the truth, since, as I have just said, no account has been taken of the effects of violent pitching motions, which must lead to still more abrupt and violent changes. Enough has been said, however, to show how important this feature of the subject is, and I will simply add that a very convenient way of expressing the effects I have been attempting to describe is afforded by the supposition that the ship is fixed, and that what may be termed 'waves of strain' roll through her structure. The introduction of this idea will help us to understand more clearly how changes in strain affect a structure, for a very small strain (considered statically), which would not affect a comparatively weak structure sensibly, if it were constantly acting in one

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direction, will suffice to destroy a far stronger structure if its direction is continually and rapidly changed."

From these quotations it is evident that the first thing we have to do, in order to obtain a further approximation in the strain question, is the complete study of the motion of a ship on waves, and thus my paper contains the solution of the following question:—"To determine the most general motion of a ship steaming with a given speed across a system of regular waves, her head making a given angle with their crests." I consider, in another paper, the strains produced by wave action, and by the effects of the ship's oscillations.

I wished to make of my paper, not an analytical exercise, but a natural sequel to Mr. Froude's paper on rolling, and to give precise answers to all the desiderata expressed in the quotation from Sir Edward Reed's paper on strains, and to expound strictly mathematical methods for the solution of the questions indicated by these authorities. It is difficult for me to judge if I have succeeded in this attempt. I am well aware of a great number of defects in my paper, and I hope the discussion will show me some new ones, which I do not know; and thus prove useful, if not for this Institution, then for myself, and for students of mine in the St. Petersburg Naval Academy, because these papers form nothing more than a translation of two chapters of my course of lectures on Theoretical Naval Architecture in that Academy.

§ 1. The oscillatory motion of a ship in a seaway, when her head makes an angle α with the direction of the running of waves, consists in a translational motion of the whole ship—the heaving—and in a rotation, which, if analysed into its three components, gives: (1) the rolling, (2) the pitching, and (3) the yawing.

It is fully explained in the Appendix how all these motions can be studied analytically, and numerically calculated for every given ship, and every value of the angle α, on a given system of waves; here I will only briefly state the results so obtained.

The heaving motion is defined if we know the motion of the centre of gravity of the ship, therefore it is sufficient to give the path which this point describes, and the law of its motion. If the ship has no onward motion her centre of gravity describes an *ellipse* by a simple harmonic motion; this ellipse is situated in the vertical plane, perpendicular to the crests of waves, *i.e.*, in the plane of the orbital motion of the particles of water. On Plate XXXII. these paths are represented for all the values of the head angle α, from point to point. When the head angle $\alpha = 90°$ the ellipse approximates very nearly to the circle described by the particles of water; if we suppose the dimensions of the ship infinitely small when compared with those of the wave it would coincide with that circle, and thus we obtain the result assumed by the late Mr. W. Froude, which is an immediate corollary of our general theory.

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If the ship has an onward motion of her own, her centre of gravity describes in space a line of spiral form, the pitch of which is equal to the space passed by the ship during a complete oscillation of her centre of gravity. Instead of representing these spirals, I have given on Plate XXXII. their base lines; it is the path which the ship's centre of gravity would describe on a vertical plane perpendicular to the crest of waves and moving uniformly with the same velocity as the speed of the ship. This plate being compared with the first one, shows, in the clearest manner, the difference in the motion of the ship's C. G. in the three cases (speed 0, 8 knots, and 10 knots). It must yet be remarked that, in the last two cases, the period of revolution is always equal to the apparent period of the wave, and thus varies with the head angle α and the velocity of the ship; the respective periods are entered on the plates, and the tables in § 15 give the numerical elements which served for the construction of these diagrams.

The ship, for which all the calculations were made, is the cruiser of the Imperial Russian Navy, *Admiral Korniloff*, of which the dimensions are :—

Length	350 ft.	= 107 metres.
Beam	48 ft. 6 in.	= 14·8 metres.
Draught	19 ft.	= 5·9 metres.
Displacement	5,000 tons.	

And the elements of the wave :—

Length	420 ft.	= 125 metres.
Height	16 ft. 6 in.	= 5 metres.
Period	9 seconds.	

§ 2. The rotational motion of the ship is analysed into its three components: the pitching, the yawing, and the rolling. The first two components, in virtue of the great resistance of water, consist, always, only of the "forced oscillation," the amplitude of which, as is shown in my first paper (1896), is almost independent of the value adopted for this resistance. It is a very favourable instance, because it enables us to calculate a very close approximation for the pitching, in spite of the very imperfect knowledge of the resistance, the pitching being the most important component in the calculations of strain.

As diagrams enable us to see at a single glance the principal features of the phenomenon, on Plate XXXIII. are represented the values of the amplitude of the pitching and rolling motion of the same ship and for all the angles of her course from point to point, and also the three velocities of the ship's onward motion. The same tables of the Appendix give the numerical elements for the construction of these diagrams.

The rolling requires a more detailed study; here the resistance of water is comparatively small, and the "free" oscillations are not extinguished with the same

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rapidity as in the case of pitching, and the motion of the ship depends on the real feature of that system of waves which produces it.

Thus, if we would consider an ideally regular system of waves of, say, a period of eight seconds, and a ship on it with a period of free oscillations of, say, twelve seconds, and if we were to start with quite definite initial conditions, say, the initial inclination and initial angular velocity equal 0, at the moment of the passage of the trough of the first wave, we could represent the motion of the ship by an analytical formula, which would show (the resistance being assumed proportional to the simple velocity) that the motion of the ship is the result of two independent oscillations, the first one with a gradually evanescent amplitude and a period of 12 seconds, and the second one with a constant amplitude and a period of 8 seconds. On Fig. 1, Plate XXXIV., the first is represented by the dotted line, the second by the thin broken line, and their resultant by the thick full line. This diagram shows that the rolling was initially non-uniform, while the "free" oscillation existed, but becomes uniform after its extinction. It is a very well known fact that, in a seaway, the rolling is almost never uniform, and thus theory seems at the first glance to be in contradiction with practice. But we must remember that the actual waves at sea are never uniform, and Mr. R. E. Froude, in his paper "On Non-Uniform Rolling" (1896), states: "And hence in proportion as, on the one hand, the resistance is small and any initial non-uniformity of rolling dies hard (so to speak) and, on the other, the non-synchronism is considerable and the alterations of amplitude rapid, the continual fresh disturbances due to the non-uniformity of swell avail effectively to maintain non-uniformity of rolling, in spite of the tendency of resistance to eradicate it." I tried to illustrate this statement by a numerical example, and the diagram, Fig. 2, Plate XXXIV., shows its results, and § 13 of the Appendix contains all the mathematical particulars. I considered a system of waves with the following successive periods:—

8·2, 7·7, 7·5, 8·5, 7·7, 8·5, 7·5, 7·7, 8·5, 7·5, 8·5, 8·5, 7·7, seconds.

Such a system would appear to every observer on board as a very uniform one, because it is impossible to distinguish fractions of seconds in observing the periods of every individual wave. Such a system would be described as a regular one with a period of 8 seconds, which is the mean of the above; but the effect of the action of this system on the ship is quite another one to that of the regular waves; the "free" oscillations no longer become extinguished, and the rolling is hardly non-uniform as exhibited on the diagram, Fig. 2, Plate XXXIV.

Thus, to calculate the rolling, we must know the actual system of waves, the cumulative action of which produces it. I believe that this example suffices to show that, on this subject, theory and practice are not in contradiction.

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As the system of waves which I considered is a regular one; or as, speaking more exactly, I considered only the action of a single individual wave of which the elements are given above, and this action is characterised by the "forced" oscillation it produces, I have represented on Plate XXXIII. the amplitude of these oscillations for the same three cases as for the pitching.

From these diagrams it is possible to draw the real positions taken by a ship on waves; it is only an exercise in projection, and I believed it unnecessary to multiply the number of plates by such drawings.

§ 3. I show in § 5 of the Appendix that the theory of rolling of the late Mr. W. Froude is but a particular case of the general one now exposed; I have only to put in the general formulæ $\alpha = 90°$, and to assume that the dimensions of the ship are very small in comparison with those of the wave, and these formulæ coincide with those of Mr. Froude. If putting $\alpha = 90°$ we consider the dimensions of the ship as finite, we obtain the analytical expressions for the co-efficients of reduction of M. Bertin, and these expressions enable us to calculate these co-efficients in a very regular and simple manner.

§ 4. When the ship is considered as infinitely small, her momentary positions of equilibrium are those when her masts coincide with the normal to the wave surface. "What are these positions for a real ship for different head angles, and different positions in respect to the crest of wave?" This position is characterised by the distance of the crest from the centre of gravity of the ship, by the elevation ζ_0 of this centre about its mean or equilibrium position on still water, and by the side inclination (heel) θ_1, and by the angle of trim ψ. These are traced on the diagram (Plate XXXVI.) for the value of $\alpha = 45°$, and the normal to the wave profile is that which passes through the ship's centre of gravity.

§ 5. There is a very important question connected with these investigations; it is that of the *stability* of a ship on waves. But I confine myself to mentioning this subject, which, for a complete treatment, would require more space than is afforded to this paper with its Appendix, and I delay it to another time.

§ 6. From this brief account of the results obtained, the reader can conclude that the behaviour of a ship in a given state of the sea can be completely calculated by a regular mathematical process, and thus all the elements required by Sir E. Reed, in the quotation I made, for the calculation of the strain will be known. On examining § 8 of the Appendix it will be remarked that these calculations are not of an unattackable complexity. It is also evident that the methods developed in the Appendix are suitable for calculating how the sea-going qualities of a ship are affected by changes in the distribution of loads, changes of trim, &c. The numerical example may perhaps be considered as unnecessary; but, dealing with such matter, I always remembered the

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following words of Fourier: "Until a numerical valuation is attained the solutions remain incomplete or useless, because the truth which we wished to discover lies concealed quite as deeply in the analytical expressions as in the physical question itself" (Théorie Analyt. de la Chaleur, § 13), and I believed that the best manner to show that the formulæ and equations are fit for such a numerical valuation was to perform it completely; thus I endeavoured in the Appendix, which is the principal part of this memoir, to be rather long and clear than short and obscure.

APPENDIX.

I HAVE explained in the paper itself the principal results of my study of the general motion of a ship on waves. Here I will expose, in a detailed manner, the methods used for this study, and it seems that a little mechanical preliminary will not be detrimental to a clearer understanding of the subject.

§ 1. It is said that the motion of a solid body is known when we can assign at every given moment t the position of every point of the body in space. Ordinarily it is performed in the following manner:—Three rectangular axes of reference $O_1\,\xi_1$, $O_1\,\eta_1$, $O_1\,\zeta_1$ fixed in space are chosen, and an arbitrary point O (Fig. 1, Plate XXXV.) of the body is taken for the origin of co-ordinate axes $O\,x$, $O\,y$, $O\,z$, fixed in the body, and thus moving with it in space, then every point M of the body will be determined in the body itself by its relative co-ordinates $x = O\,P$, $y = P\,Q$, and $z = Q\,M$, which, of course, are independent of the time t, and only change their values from one point of the body to the other. The position of the same point M in space is determined by its absolute co-ordinates $\xi_1 = O_1\,\Pi$, $\eta_1 = \Pi\,K$, and $\zeta = K\,M$; thus the problem of the study of the motion of the rigid body is reduced to expressing the absolute co-ordinates ξ_1, η_1, ζ_1 as functions of the time t and of the variables x, y, z. On drawing through the point O three axes $O\,\xi$, $O\,\eta$, $O\,\zeta$, respectively parallel to $O_1\,\xi_1$, $O_1\,\eta_1$, $O_1\,\zeta_1$, and designating by $a, b, c, a_1 \ldots c_2$ the cosines of the angles between the axes $O\,x$, $O\,y$, $O\,z$ and the former ones, according to the schedule beneath:—

	ξ	η	ζ
x	a	a_1	a_2
y	b	b_1	b_2
z	c	c_1	c_2

and by ξ_0, η_0, ζ_0 the absolute co-ordinates of the point O, so that $\xi_0 = O\,A$, $\eta_0 = A\,B$, $\zeta_0 = B\,O$, the following relations between the two series of co-ordinates of the same point M are immediately obtained:—

$$\left.\begin{aligned} \xi_1 &= \xi_0 + a\,x + b\,y + c\,z \\ \eta_1 &= \eta_0 + a_1\,x + b_1\,y + c_1\,z \\ \zeta &= \zeta_0 + a\,x + b_2\,y + c_2\,z \end{aligned}\right\} \qquad (1)$$

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Thus the determination of ξ_1, η_1, ζ_1 requires only that of ξ_0, η_0, ζ_0 and of the nine direction cosines $a, b, c \ldots c_2$; otherwise the study of the motion of the body is reduced to the study of the absolute motion of one of its *points* O, and of the *rotation* of the body about this point, as the axes O x, O y, O z only change their direction in respect to the axes O ξ, O η, O ζ, which move in space, remaining parallel to themselves. The nine cosines are not independent of one another, six well-known relations existing between them; but, as Euler has shown, it is simpler not to use these relations, but to express all the nine cosines in functions of three independent angles ψ, ϕ, θ, called the Eulerian angles. These angles, as will be found in every treatise on theoretical mechanics or solid geometry, are generally defined in the following manner: a sphere of an arbitrary radius is described from the point O as centre, and the points of the intersection of its surface with the axes are marked; the co-ordinate planes cut this surface along great circles. Let O N be the one half of the line of intersection of the planes x O y and ξ O η, the position of this line is determined by the angle $\psi = \xi$ O N, reckoned from O ξ in the direction of O η from 0° to 360° (Fig. 2, Plate XXXV.); the position of the axis $o x$ in the plane x O y is determined by the angle $\phi =$ N O x, reckoned from O N in the direct way; it is thus that the angle N O y would be equal to $\frac{\pi}{2} + \phi$; and, at last, the inclination of the plane x O y to the plane ξ O η is defined by the angle θ, reckoned in the sense of the positive rotations about O N. In adopting such a definition of the Eulerian angles ϕ, ψ, θ, the positive angular velocities ϕ', ψ', θ' are to be laid on the positive parts of the axes O , O ζ, and on the line O N. It is necessary to state precisely the direction in which the angles ϕ, ψ, θ are reckoned as positive, to avoid errors in sign.

These three angles ψ, ϕ, θ determine completely, and in a single manner, the position of the moving axes in respect to the fixed ones.

Applying the fundamental formulæ of spherical trigonometry, the following expressions of the nine direction cosines are obtained:—

$$\left.\begin{aligned}
a &= \cos(\widehat{x\,\xi}) = \cos\psi\cos\phi - \sin\psi\sin\phi\cos\theta \\
a_1 &= \cos(\widehat{x\,\eta}) = \sin\psi\cos\phi + \cos\psi\sin\phi\,.\cos\theta \\
a &= \cos(\widehat{x\,\zeta}) = \sin\phi\sin\theta \\
b &= \cos(\widehat{y\,\xi}) = -\cos\psi\sin\phi - \sin\psi\cos\phi\,.\cos\theta \\
b_1 &= \cos(\widehat{y\,\eta}) = -\sin\psi\sin\phi + \cos\psi\cos\phi\cos\theta \\
b_2 &= \cos(\widehat{y\,\zeta}) = \cos\phi\sin\theta \\
c &= \cos(\widehat{z\,\xi}) = \sin\psi\sin\theta \\
c_1 &= \cos(\widehat{z\,\eta}) = -\cos\psi\sin\theta \\
c_2 &= \cos(\widehat{z\,\zeta}) = \cos\theta
\end{aligned}\right\} \qquad (2)$$

These are called the Eulerian geometrical equations.

On designating by p, q, r the components of the body's angular velocity on the axes O x, O y, O z, the following equations express the relations between p, q, r and the Eulerian angles ψ, ϕ, θ and their derivatives ψ', ϕ', θ':—

$$\left.\begin{aligned}
p &= \psi'\sin\phi\sin\theta + \theta'\cos\phi \\
q &= \psi'\cos\phi\sin\theta - \theta'\sin\phi \\
r &= \phi' + \psi'\cos\theta
\end{aligned}\right\} \qquad (3)$$

All the above formulæ (1, 2, 3) express only geometrical and cinematical relations, and the choice of the point O is, as will be easily remarked, quite indifferent; but, if we pass to the dynamics, it is quite another thing, and, if it is wished to obtain the equations of the motion of the body in their simplest form, the point O is to be taken in the body's centre of gravity, because, in this case, the

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equations of motion of this point can immediately be written down, the forces which act on the solid being supposed given. These equations are :—

$$M\frac{d^2\xi_0}{dt^2} = \Sigma\Xi; \qquad M\frac{d^2\eta_0}{dt^2} = \Sigma H; \qquad M\frac{d^2\zeta_0}{dt^2} = \Sigma Z \qquad (4)$$

where M is the mass of the solid, and $\Sigma\Xi$, ΣH, ΣZ are the sums of the components on the axes $O\xi$, $O\eta$, $O\zeta$ of all the forces acting on the body.

It is to be remarked that in these equations the unknown quantities ψ, ϕ, θ, and their derivatives interfere only in the right-hand members when the forces are dependent, either on the position of the body or the velocities of certain points of it, if it moves in a resisting medium.

A second set of equations is necessary to ascertain the rotation of the body about its centre of gravity. These equations take their simplest form if the axes Ox, Oy, Oz, fixed in the body, be chosen in a convenient manner ; as Euler has shown, it is the principal axes of inertia of the solid which are to be taken as axes of reference, and then the equations of the rotary motion are :—

$$\left.\begin{aligned} A\frac{dp}{dt} + (C - B)\,qr &= \Sigma(yZ - zY) \\ B\frac{dq}{dt} + (A - C)\,rp &= \Sigma(zX - xZ) \\ C\frac{dr}{dt} + (B - A)\,pq &= \Sigma(xY - yX) \end{aligned}\right\} \qquad (5)$$

where A, B, C are the principal moments of inertia of the body about the axes Ox, Oy, Oz ; p, q, r, the corresponding components of the angular velocity on the same axes, and the right-hand sum is the resultant moments of the forces acting on the body.

The systems of equations (4, 5) and the system (3), which must be joined to the first two with the initial conditions, define completely the motion of the body ; but, unfortunately, their integration, in the general case, overwhelms the forces of mathematical analysis.

§ 2. Returning to the case of the ship, we will try to deduce some useful conclusions from the elementary mechanical principles above. In the first instance we see that we must take for the origin of axes of co-ordinates fixed in the ship her centre of gravity, and for the axes themselves her principal axes of inertia. We can always assign exactly one of these axes, namely, that which is perpendicular to the longitudinal plane of the ship ; such an axis must exist, because this plane is not only a plane of symmetry of the forms but also of loads. The other two axes lie in that plane. On large ships of the forms now usual, the centre of gravity of the ship lies close to her middle section, and the forms of the ship are *grosso modo* symmetrical in respect to this plane, and the principal loads balanced in a manner also nearly symmetrical. If this symmetry were an exact one the middle section would be a principal plane and its intersection with the longitudinal one a principal axis of inertia ; then, as the third one is perpendicular to the other two, its position would also be known. If we assume that our ship has the above-mentioned double symmetry, we shall not be far from truth, and we shall avoid the tedious work of calculating the exact position of her principal axes. Secondly, we must choose the Eulerian angles in a convenient manner for our special purpose, in order to obtain the simplest set of equations. Looking at Fig. 2, Plate XXXV., and the formulæ (2), which are a consequence of it, we shall remark that, in respect to the Eulerian angles, the axes take different parts, as all is referred to the line O N of the intersection of the planes $x\,O\,y$ and $\xi\,O\,\eta$, which may be called the two fundamental planes. It is well known that it is very favourable to have

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in the equations, both ordinary and differential, for the unknowns sought for, such quantities as we could assign the limits of variation to, this advantage becoming of real importance when the said limits are closely restricted. For large ships the pitching rarely attains 10°, the angle of change of course (yawing) is generally less than 5°, and only the angle of rolling can reach 20°, or even more; thus the longitudinal axis of the ship deviates from its mean position by nearly 10°, the other two axes may deviate from their mean positions up to 20°, or even more, for heavier rolling. It is natural to take for the axes fixed in space $O_1\xi_1$, $O_1\eta_1$, $O_1\zeta_1$, the mean, or equilibrium positions of the corresponding axes fixed in the ship. To make a due choice of the Eulerian angles we shall be guided by the following reasons: if we take for the two fundamental planes two corresponding planes, such as would coincide when the ship passes through her upright position, the angle θ of their inclination to one another would have a restricted variation; but, on account of the smallness of this angle, a little change in the position of the plane itself might lead to large changes in the values of the angles ψ and ϕ, which, therefore, would not be contained within restricted limits. This will not be the case if we take for the two fundamental planes two planes such as are perpendicular in the upright position of the ship; then, in every position of the ship which is close to the upright, these planes will form an angle but little different from 90°, and all the three Eulerian angles will be contained within restricted limits.

Thus we will take for one of our fundamental planes the upright position of the longitudinal plane of the ship ($O_1\ \xi_1\ \zeta_1$), and for the other her flotation L.W.L.; these two planes, in spite of the motion of the ship, will always intersect at an angle differing little from 90°, so that θ will be close to 90°, and the other two angles ψ and ϕ will not exceed 10°. It remains only to state precisely the direction in which every one of these angles is to be reckoned as positive.

The axes fixed in the ship may be taken as follows: the longitudinal plane of the ship for the plane $x\,O\,z$, the middle section for the plane $y\,O\,z$, the axis $O\,y$ directed to the *port* side, and $O\,z$ downwards; and then the Eulerian angles that we choose are: $\psi = \xi\,O\,N$ is the angle contained between the axis $O\,\xi$ and the line $O\,N$ of the intersection of the planes $\xi\,O\,\zeta$ and $x\,O\,y$ (Fig. 3, Plate XXXV.); it is reckoned as positive from $O\,\xi$ in the sense of direct rotations round $O\,\eta$ as shown by the arrow. The angle $\phi = N\,O\,x$, and is contained in the plane $x\,O\,y$ between the line $O\,N$ and the axis $O\,x$, and is reckoned positively from $O\,N$ in the direct sense, so that the angle $N\,O\,y = 90° + \phi$ (algebraically). The angle θ is the spherical angle $K\,N\,x$, or the inclination of the plane $\xi\,O\,\zeta$ and $x\,O\,y$; it is to be reckoned positively in the sense of direct rotations round $O\,N$.

This being admitted, we obtain immediately the following two groups of formulæ:—(6) for the cosines—

$$\left.\begin{aligned}
a &= \cos(x\xi) = \cos\phi\cos\psi - \sin\phi\sin\psi\cos\theta\\
a_1 &= \cos(x\eta) = \sin\phi\sin\theta\\
a_2 &= \cos(x\zeta) = -\cos\phi\sin\psi - \sin\phi\,.\cos\psi\,.\cos\theta\\
b &= \cos(y\xi) = -\sin\phi\,.\cos\psi - \cos\phi\sin\psi\cos\theta\\
b_1 &= \cos(y\eta) = \cos\phi\sin\theta\\
b_2 &= \cos(y\zeta) = \sin\phi\sin\psi - \cos\phi\cos\psi\cos\theta\\
c &= \cos(z\xi) = \sin\psi\sin\theta\\
c_1 &= \cos(z\eta) = \cos\theta\\
c_2 &= \cos(z\zeta) = \cos\psi\sin\theta
\end{aligned}\right\} \qquad (6)$$

and (7) for the angular velocities—

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$$\left.\begin{aligned} p &= \theta' \cos\phi + \psi' \cos(x\eta) = && \psi' \sin\phi \sin\theta + \theta' \cos\phi \\ q &= \theta' \cos\left(\frac{\pi}{2} + \phi\right) + \psi' \cos(y\eta) = && \psi' \cos\phi \sin\theta - \theta' \sin\phi \\ r &= \phi' + \psi' \cos(z\eta) = && \phi' + \psi' \cos\theta \end{aligned}\right\} \qquad (7)$$

The first group of formulæ can be obtained in two manners, either by applying the fundamental formula of spherical trigonometry to the triangles—

$$N x\xi, \quad N x\eta, \quad N x\zeta; \qquad N\xi y, \quad N\eta y, \quad N\zeta y; \qquad \xi\eta z, \quad \eta z\zeta,$$

and remarking that the arc $\eta z = \theta$ and the angle $\zeta\eta z = \psi$; or, by successive transformation of co-ordinates by three rotations effected one after the other: (1) about the axis $O\eta$ on the angle ψ, then the axis ξ coincides with O N, (2) about the line O N on the angle $\theta - \frac{\pi}{2}$, after which the plane $\xi O\eta$ will coincide with the plane $x O y$ and the axis ζ with z, and (3) about the axis Oz on the angle ϕ which finally brings the system of axes $O\xi\eta\zeta$ in superposition to $O x y z$. On establishing the formulæ (6) in this last manner, we shall see that they are perfectly general, and the angles ϕ, ψ, θ may have every positive or negative value.

It is this particular choice of the Eulerian angles which enables us to apply to the solution of our problem the method of successive approximations and development in series. It will be easily remarked that ψ is nearly the angle of pitching, thus less than 10°; ϕ is the angle of change of course (yawing), which is less than ψ, and $\theta_1 = \theta - \frac{\pi}{2}$, the angle of rolling. Then, with an error which is less than $1\frac{1}{2}$ per cent., we can assume $\sin\psi = \psi$; $\cos\psi = 1$; $\sin\phi = \phi$; $\cos\phi = 1$; if the angle of rolling does not surpass 20°, we shall have $\sin\theta_1 = \theta_1$. As arc 20° = 0·342, and $\sin\theta_1 = 0{\cdot}349$ and $\cos\theta_1 = 0{\cdot}940$; for 30° we have arc 30° = 0·524, and sin 30° = 0·5, cos 30° = 0·866; thus, if the angle of rolling does not exceed 10° to 12°, we can take $\sin\theta_1 = \theta_1$ and $\cos\theta_1 = 1$; if it is near to 20°, we can take $\sin\theta_1 = \theta_1$; but $\cos\theta_1 = 1 - \frac{\theta_1^2}{2}$; this will be the second approximation, and so on.

To effect the developments we will regard the quantities ϕ, ψ, θ, and their derivatives ϕ', ψ', θ' as small quantities of the first order; to obtain the first approximation we will retain only their first powers and neglect all the higher ones and their mutual products; for the second approximation we will retain the first two powers, and so on.

Then from the formulæ (6) we shall have the following schedule of the cosines exact to terms of the second order:—

	ξ	η	ζ
x	$1 - \frac{\phi^2}{2} - \frac{\psi^2}{2}$	ϕ	$-\psi + \phi\theta_1$
y	$-\phi + \psi\theta_1$	$1 - \frac{\theta_1^2}{2} - \frac{\phi^2}{2}$	$\theta_1 + \phi\psi$
	ψ	$-\theta_1$	$1 - \frac{\theta_1^2}{2} - \frac{\psi^2}{2}$

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and for the angular velocities—

$$\left.\begin{aligned} p &= \theta_1' + \phi\,\psi' \\ q &= \psi' - \phi\,\theta_1' \\ r &= \phi' - \theta_1\,\psi' \end{aligned}\right\} \qquad (8)$$

In the first approximation, which corresponds to Froude's theory of rolling with Bertin's reductions, the schedules would be :—

	ξ	η	ζ
x	1	ϕ	$-\psi$
y	$-\phi$	1	θ_1
z	ψ	$-\theta_1$	1

(9′)

and—

$$\left.\begin{aligned} p &= \theta_1' \\ q &= \psi' \\ r &= \phi' \end{aligned}\right\} \qquad (9)$$

and the six approximate differential equations of the motion of the ship will be

$$\left.\begin{aligned} &M\frac{d^2\xi_0}{dt^2} = \Sigma\,\Xi; \qquad M\frac{d^2\eta_0}{dt^2} = \Sigma\,H; \qquad M\frac{d^2\zeta_0}{dt^2} = \Sigma\,Z \\ &A\,\theta_1'' = \Sigma\,(y\,Z - z\,Y); \qquad B\,\psi'' = \Sigma\,(z\,X - x\,Z); \qquad C\,\theta_1'' = \Sigma\,(x\,Y - y\,X) \end{aligned}\right\} \qquad (10)$$

the letters having the same meaning as in equations (4) and (5) above.

We will give here the whole development of this first approximation, the second one is a little abstruse, and is not of great importance for our present subject, but its consideration is necessary when dealing with stability on waves, and I will postpone it till the special paper which I intend to prepare on this important subject.

§ 3. Let us consider a ship whose head makes an angle α with the direction of the running of waves. We have already explained the choice of the co-ordinate axes. The position of the ship in space in respect to the fixed axes $O_1\xi_1$, $O_1\eta_1$, $O_1\zeta_1$ is determined by the absolute co-ordinates ξ_0, η_0, ζ_0 of her centre of gravity, and by the three Eulerian angles ψ, θ, ϕ, which represent at the same time nearly the angles of pitching, rolling, and yawing. In order to solve the equations (10) it is necessary to form explicit expressions of their right-hand terms as functions of ξ_0, η_0, ζ_0, ψ, θ, ϕ, their derivatives, and the time t.

The forces acting on the ship are: (1) Her weight, (2) the hydrodynamical pressure, (3) the resistance of water to the oscillatory motion of the ship. To calculate the support and the moments of support which proceed from the hydrodynamical pressure we could use two methods: one is perfectly general, and is explained in my paper on pitching, the second is of a more elementary character, and is in closer connection with Mr. Froude's paper. As this last method, although a longer one as to developments, furnishes a clearer image of the physical meaning of the first approximation, we will use it in this paper.

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The single hypothesis which is necessary for our theory is the same as that made to treat the pitching: the pressure which acts on the ship in every point of her submerged surface is that which takes place in the corresponding point of the wave, supposed to be trochoidal.

If we develop in series the exact expressions of the resultant wave support and the resultant moments, the first approximation is equivalent to the following expression of the above-mentioned hypothesis: (1) the hydrodynamical support, proceeding from an element of volume, has the direction of the normal to the momentary surface of dynamical level passing through the corresponding point, and bears to the weight of the displaced matter the same ratio as the length of the above-mentioned normal to the radius of the rolling circle of the trochoid, which forms the profile of the level surface; (2) The trochoidal profile can be replaced by the corresponding sinusoidal one; (3) The exact system of dynamical level surfaces can be replaced by a set of cylindrical surfaces parallel to that which forms the free waving surface of water.

These hypotheses are the same as made by Mr. W. Froude for rolling; but, as we do not need to suppose that the dimensions of the ship are infinitely small as compared with that of the wave, our first approximation corresponds, not only to the theory of Mr. W. Froude, but includes the principal reductions of M. Bertin, especially if we take for the profile of our set of level surfaces, not the sinusoid which corresponds to the trochoid of the free surface of water, but to the trochoid passing through the ship's centre of buoyancy.

Let Fig. 4, Plate XXXV., represent the projection on the plane $\xi_1 O \eta_1$ of the crest of two successive waves and their section by the plane $\zeta_1 O_1 \chi_1$; and we have to write down the equation of the wave surface at the instant t, referred to absolute co-ordinates $\xi_1 \eta_1 \zeta_1$. If we draw in the plane $\xi_1 O_1 \eta_1$, which we will suppose to be the plane of still water surface, two auxiliary axes $O_1 \chi_1$ and $O_1 \sigma_1$, the last parallel to the crest and the first in the direction of the running of the waves, the equation of the sinusoidal wave profile will be—

$$\zeta_1 = r \cos 2\pi \left(\frac{\chi_1}{\lambda} - \frac{t}{\tau} \right)$$

where λ is the length of the wave, r the radius of the generating circle, or half the height of wave, and τ the period. If the ship has no onward motion, τ is the true period; in the other cases the apparent one. The time t is to be reckoned from the moment of the passage of a hollow of the wave through the axis $O_1 \zeta_1$. But we have—

$$\chi_1 = \xi_1 \cos a + \eta_1 \sin a ;$$

thus—

$$\zeta_1 = r \cos 2\pi \left(\frac{\xi_1 \cos a}{\lambda} + \frac{\eta_1 \sin a}{\lambda} - \frac{t}{\tau} \right) \qquad (12)$$

On putting

$$\lambda_1 = \frac{\lambda}{\cos a} \text{ and } \lambda_2 = \frac{\lambda}{\sin a} \qquad (13)$$

we bring the equation of the wave surface referred to the axes $O_1 \xi_1$, $O_1 \eta_1$, $O_1 \zeta_1$ into the form—

$$\zeta = r \cos 2\pi \left(\frac{\xi_1}{\lambda_1} + \frac{\eta_1}{\lambda_2} - \frac{t}{\tau} \right) \qquad (14)$$

It may be remarked that λ_1 and λ_2 are the lengths K N and P Q, which may be called the effective head length and the effective cross length of the wave for the considered course a of the ship.

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From equation (14) we have the following expressions of the cosines of the angles formed by the normal to this surface with the axes—

$$\left.\begin{aligned}
\operatorname{Cos}(\overset{\wedge}{n\,\xi_1}) &= -\frac{\frac{2\pi r}{\lambda_1}\sin U}{\sqrt{1+\frac{4\pi^2 r^2}{\lambda^2}\sin^2 U}}\\
\operatorname{Cos}(\overset{\wedge}{n\,\eta_1}) &= -\frac{\frac{2\pi r}{\lambda_2}\sin U}{\sqrt{1+\frac{4\pi^2 r^2}{\lambda^2}\sin^2 U}}\\
\operatorname{Cos}(n\,\zeta_1) &= -\frac{1}{\sqrt{1+\frac{4\pi^2 r^2}{\lambda^2}\sin^2 U}}
\end{aligned}\right\} \qquad (15)$$

the (−) sign being taken as corresponding to the upward direction of the normal, and U denoting the argument

$$2\pi\left(\frac{\xi_1}{\lambda_1}+\frac{\eta_1}{\lambda_2}-\frac{t}{\tau}\right).$$

For the steepest large waves the quantity $\frac{2\pi r}{\lambda}$ is nearly $\frac{1}{7}$; thus with the same degree of approximation as in our other formulæ we can consider this quantity as a small one of the first order, and neglect its squares and higher powers; then we shall simply have for our first approximation

$$\operatorname{Cos}(\overset{\wedge}{n\,\xi_1}) = -\frac{2\pi r}{\lambda_1}\sin U; \qquad \cos(\overset{\wedge}{n\,\eta_1}) = -\frac{2\pi r}{\lambda_2}\sin U; \qquad \cos(\overset{\wedge}{n\,\zeta_1}) = -1. \qquad (16)$$

The inclination C A M of the normal (Fig. 5, Plate XXXV.) being less than 9°, we can take, instead of the ratio $\frac{A\,M}{A\,C}$ of the normal to the radius of the rolling circle, the ratio $\frac{A\,N}{A\,C}$. Then, as the angle N C M is the phase U, and $A\,C = R = \frac{\lambda}{2\pi}$, and $C\,M = r$, we have

$$A\,N = R + r\cos U = R\left(1+\frac{2\pi r}{\lambda}\cos U\right)$$

and

$$\frac{A\,N}{R} = 1+\frac{2\pi r}{\lambda}\cos U. \qquad (17)$$

Then, according to the hypotheses on wave support, we obtain the following expressions of the components $\Xi\rho\,d\,v$, $H\rho\,d\,v$, and $Z\rho\,d\,v$ of this force proceeding from the element $d\,v$ of the submerged volume, at the point of which the co-ordinates are ξ_1 and η_1, the value of the third co-ordinate ζ_1 being indifferent, according to the third hypothesis—

$$\left.\begin{aligned}
\Xi &= g\left(1+\frac{2\pi r}{\lambda}\cos U\right)\cos(\overset{\wedge}{n\,\xi_1}) = -\frac{2\pi r}{\lambda_1}g\sin U\\
H &= g\left(1+\frac{2\pi r}{\lambda}\cos U\right)\cos(\overset{\wedge}{n\,\eta_1}) = -\frac{2\pi r}{\lambda_2}g\sin U\\
Z &= g\left(1+\frac{2\pi r}{\lambda}\cos U\right)\cos(n\,\zeta) = -g\left(1+\frac{2\pi r}{\lambda}\cos U\right)
\end{aligned}\right\} \qquad (18)$$

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where terms of higher orders are rejected; ρ denotes the density of water and g the acceleration of gravity.

The components on the axes ξ_1, η_1, ζ_1, of the resultant wave support for the whole ship, which we will denote by P_ξ, P_η, and P_ζ, will be—

$$P_\xi = \rho \int_v \Xi \, dv; \qquad P_\eta = \rho \int_v H \, dv; \qquad P_\zeta = \rho \int_v Z \, dv$$

where the integrals are to be extended for the whole submerged volume at the moment t.

On putting for Ξ, H, Z their values (18), we obtain—

$$\left.\begin{aligned} -P_\xi &= \frac{2\pi r}{\lambda_1} g\rho \int \sin U \, dv \\ -P_\eta &= \frac{2\pi r}{\lambda} g\rho \int_v \sin U \, dv \\ -P_\zeta &= g\rho V + \frac{2\pi r}{\lambda} g\rho \int_v \cos U \, dv \end{aligned}\right\} \qquad (19)$$

Thus all is reduced to the calculation of the submerged volume V and of the two integrals—

$$\int_v \sin U \, dv \text{ and } \int_v \cos U \, dv.$$

As the data for these calculations can only be taken from the drawings of the ship, we must, instead of the co-ordinates ξ, η, ζ, introduce the co-ordinates $x\,y\,z$; we have for this the formulæ (1) and the schedule (9′), which give :—

$$\left.\begin{aligned} \xi_1 &= \xi_0 + x - y\phi + z\psi \\ \eta_1 &= \eta_0 + x\phi + y - z\theta_1 \\ \zeta_1 &= \zeta_0 - x\psi + y\theta_1 + z \end{aligned}\right\} \qquad (20)$$

and thus the argument U will be—

$$U = 2\pi \left[\frac{\xi_0 + x - y\phi + z\psi}{\lambda_1} + \frac{\eta_0 + x\phi + y - z\theta_1}{\lambda_2} - \frac{t}{\tau} \right]$$

$$= 2\pi \left[\left(\frac{\xi_0}{\lambda_1} + \frac{\eta_0}{\lambda_2}\right) + \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau}\right) + \left(\frac{x}{\lambda_2} - \frac{y}{\lambda_1}\right)\phi + \left(\frac{z}{\lambda_1}\psi - \frac{z}{\lambda_2}\theta_1\right) \right]$$

the quantities $\frac{\xi_0}{\lambda_1}$ and $\frac{\zeta_0}{\lambda_2}$ are not greater than $\frac{r}{\lambda_1}$ and $\frac{r}{\lambda_2}$, thus they can be regarded as small ones of the first order, as all the unknowns of our problem; but the integrals which contain sin U and cos U are multiplied by the small factor $\frac{2\pi r}{\lambda}$, and thus the terms which will proceed in the expressions of P_ξ, P_η, P_ζ from the terms of the first order in U, will be of the second order and need not be calculated, to be afterwards rejected in the first approximation. We shall obtain this approximation directly on putting :—

$$U = 2\pi \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau}\right)$$

which is the finite part of the above expression. Then—

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$$\text{Sin U} = \left(\sin\frac{2\pi x}{\lambda_1}\cos\frac{2\pi y}{\lambda_2} + \cos\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\right)\cos\frac{2\pi t}{\tau}$$
$$- \left(\cos\frac{2\pi x}{\lambda_1}\cos\frac{2\pi y}{\lambda_2} - \sin\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\right)\sin\frac{2\pi t}{\tau};$$
$$\text{Cos U} = \left(\cos\frac{2\pi x}{\lambda_1}\cos\frac{2\pi y}{\lambda_2} - \sin\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\right)\cos\frac{2\pi t}{\tau}$$
$$+ \left(\sin\frac{2\pi x}{\lambda_1}\cos\frac{2\pi y}{\lambda_2} + \cos\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\right)\sin\frac{2\pi t}{\tau},$$

which, being substituted in formulæ (19), reduce the calculation of the above integrals to the following ones :—

$$\left.\begin{aligned} I_1 &= \int_v \cos\frac{2\pi x}{\lambda_1}\cos\frac{2\pi y}{\lambda_2}\,dv; & I_2 &= \int_v \sin\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\,dv \\ I_3 &= \int_v \cos\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\,dv; & I_4 &= \int_v \sin\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\,dv \end{aligned}\right\} \quad (21)$$

All these integrals relate to the whole submerged volume V. This volume can be decomposed into two parts : (1) the constant volume V_0, representing the displacement of the ship, and contained between her keel and load-water line AB ; and (2) the variable part V_t of the submerged volume, contained between the load-water line and the momentary position of the surface of water. Thus every one of the integrals (21) will be decomposed into two parts, relating to the Volumes V′ and V_t, so that—

$$\int_v = \int_{v_0} + \int_{v_t}$$

The first part which relates to V_0 is immediately calculable, and we shall obtain—

$$\left.\begin{aligned} A_0' &= \int_{v_0}\cos\frac{2\pi x}{\lambda_1}\cos\frac{2\pi y}{\lambda_2}\,dv = \int_0^h dz\int_{-L}^{+L}\cos\frac{2\pi x}{\lambda_1}\,dx\int_{-y}^{+y}\cos\frac{2\pi y}{\lambda_2}\,dy \\ &= \frac{\lambda_2}{\pi}\int_0^h dz\int_{-L}^{+L}\sin\frac{2\pi y}{\lambda_2}\cos\frac{2\pi x}{\lambda_1}\,dx \\ B_0' &= \int_{v_0}\sin\frac{2\pi x}{\lambda_1}\cos\frac{2\pi y}{\lambda_2}\,dv = \int_0^h dz\int_{-L}^{+L}\sin\frac{2\pi x}{\lambda_1}\,dx\int_{-y}^{+y}\cos\frac{2\pi y}{\lambda_2}\,dy \\ &= \frac{\lambda_2}{\pi}\int_0^h dz\int_{-L}^{+L}\sin\frac{2\pi x}{\lambda_1}\cdot\sin\frac{2\pi y}{\lambda_2}\,dx \end{aligned}\right\} \quad (22)$$

where L is half the length of the ship, h her draught, and y the ordinate of that point of her surface of which the other two co-ordinates are x and z, and is to be taken from the body plan of the ship.

The integrals—

$$\int_{v_0}\cos\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\,dv, \text{ and } \int_{v_0}\sin\frac{2\pi x}{\lambda_1}\sin\frac{2\pi y}{\lambda_2}\,dv$$

will be identically equal to zero.

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It is easy to conclude that the integrals relating to V_t in the expressions—

$$\int_v \cos U \, d v \text{ and } \int_v \sin U \, d v$$

will not furnish terms of the first order, but only of the second and higher ones, because the volume V_t is evidently equal to zero when the variables $\xi_0, \eta_0, \zeta_0, \phi, \psi, \theta$, and the constant parameter $\frac{2\pi r}{\lambda}$ are annulled: and, as it can only contain integer powers of all these quantities, it is, at least, of the first order in respect to them, and the two integrals being afterwards multiplied by the small factor $\frac{2\pi r}{\lambda}$, which is also of the first order, their parts relating to V_t will furnish only terms of the second and higher orders, and we need not calculate them for our first approximation.

Thus it remains only to calculate the volume V_t, itself, entering into the expression of P_ζ. This volume relates to the parts of the ship close to the load-water line, and we can assume these as cylindical and perpendicular to the plane of the L.W.L. This supposition is very near to the truth for ships of the commercial marine and for most men-of-war, except those of the French navy with re-entering forms, for which a correction is required. This correction is to be performed in an analogous maunner, as is explained in my paper on pitching, and I will not develop it in detail here.

The volume V_t contained between the L.W.L., or the plane x O y and the surface of water—

$$\zeta_1 = r \cos U$$

is expressed by the integral—

$$V_t = -\int_{-L}^{+L} d x \int_{-y_0}^{+y_0} z_1 \, d y$$

where y_0 is the ordinate of the L.W.L. corresponding to the abscissæ value x, and z_1 is the ordinate of the surface of water corresponding to the point (x, y), and reckoned from the plane x O y; the (—) sign being taken because V_t denotes the additional immersed volume, and the ordinates z_1 are reckoned positively in the downward direction. To calculate this integral we must form an explicit expression for z_1.

We have the general relation:—

$$\zeta_1 = \zeta_0 - x \psi + y \theta_1 + z,$$

and—

$$U = 2\pi \left[\left(\frac{\xi_0}{\lambda_1} + \frac{\eta_0}{\lambda_2} \right) + \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau} \right) + \left(\frac{x}{\lambda_2} - \frac{y}{\lambda_1} \right) \phi + \left(\frac{z}{\lambda_1} \psi - \frac{z}{\lambda_2} \theta_1 \right) \right];$$

on substituting this value in the equation $\zeta_1 = r \cos U$ of the wave surface, and writing z_1 instead of z, we obtain for the determination of z_1 the following equation:—

$$\zeta_0 - x \psi + y \theta_1 + z_1 = r \cos 2\pi \left[\left(\frac{\xi_0}{\lambda_1} + \frac{\eta_0}{\lambda_2} \right) + \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau} \right) + \left(\frac{x}{\lambda_2} - \frac{y}{\lambda_1} \right) \phi + \left(\frac{z_1}{\lambda_1} \psi - \frac{z_1}{\lambda_2} \theta_1 \right) \right]$$

from which we have, on keeping only the terms of the first order—

$$Z_1 = -\zeta_0 + x \psi - y \theta_1 + r \cos 2\pi \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau} \right) \qquad (24)$$

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which gives for V_t—

$$V_t = -\int_{-L}^{+L} dx \int_{y_0}^{+y_0} (-\zeta_0 + x\psi - y\theta_1)\, dy - r\int_{-L}^{+L} dx \int_{-y_0}^{+y_0} \cos 2\pi \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau}\right) dy$$

$$= \zeta_0 S - \psi S.l - \frac{\lambda_2}{\pi} r \int_{-L}^{+L} \sin \frac{2\pi y_0}{\lambda_2} \cos 2\pi \left(\frac{x}{\lambda_1} - \frac{t}{\tau}\right) dx$$

$$= \zeta_0 S - \psi S l - r a_0' \cos \frac{2\pi t}{\tau} - r b_0' \sin \frac{2\pi t}{\tau} \qquad (25)$$

where we have put—

$$S = 2\int_{-L}^{+L} y_0\, dx = \text{the area of the L.W.L.}$$

$$S l = 2\int_{-L}^{+L} x\, y_0\, dx = \text{the moment of S about the transverse axis.}$$

$$a_0' = \frac{\lambda_2}{\pi}\int_{-L}^{+L} \sin \frac{2\pi y_0}{\lambda_2} \cos \frac{2\pi x}{\lambda_1} dx; \qquad b_0' = \frac{\lambda_2}{\pi}\int_{-L}^{+L} \sin \frac{2\pi y_0}{\lambda_2} \sin \frac{2\pi x}{\lambda_1} dx \qquad (26)$$

Taking into consideration the formulæ (21), (22), (25), the following expressions of the resultant wave support will be obtained :—

$$\left.\begin{aligned} P\xi &= -\frac{2\pi r}{\lambda_1} g\rho \int_v \sin U\, dv = -\frac{2\pi r}{\lambda_1} g\rho \left[B_0' \cos \frac{2\pi t}{\tau} - A_0' \sin \frac{2\pi t}{\tau}\right] \\ P\eta &= -\frac{2\pi r}{\lambda_2} g\rho \int_v \sin U\, dv = -\frac{2\pi r}{\lambda_2} g\rho \left[B_0' \cos \frac{2\pi t}{\tau} - A_0' \sin \frac{2\pi t}{\tau}\right] \\ P\zeta &= -g\rho V_0 - g\rho \left(\zeta_0 S - \psi S l - r a_0' \cos \frac{2\pi t}{\tau} - r b_0' \sin \frac{2\pi t}{\tau}\right) \\ &\quad - \frac{2\pi r}{\lambda} g\rho \left[A_0' \cos \frac{2\pi t}{\tau} + B_0' \sin \frac{2\pi t}{\tau}\right] \end{aligned}\right\} \qquad (27)$$

It may be remarked about these expressions that $P\xi$, $P\eta$, and the last term $P\zeta$, represent the components of additional support resulting from the difference of the pressure in the wave from the hydrostatical pressure, and relating to the submerged volume V_0. According to an elegant theorem due to M. Guyou, if this additional force be represented by a vector, its extremity would describe a circle. This is really the case for our formulæ (27), because $P\eta = P\xi . \frac{\lambda_2}{\lambda_1} = P\xi . tg\, a$, which shows that the said force, or vector, is always contained in the plane $\eta_1 = \xi_1\, tg\, a$, the plane of the profile of the wave ; and at the same time the sum :—

$$P\xi^2 + P\eta^2 + P\zeta^2 = \frac{4\pi^2 r^2}{\lambda_1^2}\left[B_0' \cos \frac{2\pi t}{\tau} - A_0' \sin \frac{2\pi t}{\tau}\right]^2 + \frac{4\pi^2 r^2}{\lambda_2^2}\left[B_0' \cos \frac{2\pi t}{\tau} - A_0' \sin \frac{2\pi t}{\tau}\right]^2$$

$$+ \frac{4\pi^2 r^2}{\lambda^2}\left[A_0' \cos \frac{2\pi t}{\tau} + B_0' \sin \frac{2\pi t}{\tau}\right]^2 = \frac{4\pi^2 r^2}{\lambda^2}\left[A_0'^2 + B_0'^2\right]$$

is a constant one. It is a remarkable fact that this result is a strictly true one, and the formulæ (27) from which we have obtained it are only approximate, as all the terms of higher orders have been neglected. This fact is an indication that our first approximation takes a true account

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of the progress of the phenomenon considered, and the error can only relate to its magnitude and not to its general course. Substituting the expressions (27) into the equations (10) and remembering that the mass of the ship is equal to $\frac{g\rho V_0}{g}$, and denoting by R_ξ, R_η, R_ζ the respective components of the resistance of water to the oscillations of the ships, we obtain the following equations of the motion of her centre of gravity, or of her general heaving motion :—

$$\left.\begin{aligned}
\frac{V_0}{g}\frac{d^2\xi_0}{dt^2} &= -\frac{2\pi r}{\lambda_1}\left[B_0'\cos\frac{2\pi t}{\tau} - A_0'\sin\frac{2\pi t}{\tau}\right] - R_\xi' \\
\frac{V_0}{g}\frac{d^2\eta_0}{dt^2} &= -\frac{2\pi r}{\lambda_2}\left[B_0'\cos\frac{2\pi t}{\tau} - A_0'\sin\frac{2\pi t}{\tau}\right] - R_\eta \\
\frac{V_0}{g}\frac{d^2\zeta_0}{dt} + S\zeta_0 &= \psi S l + r\left(a_0'\cos\frac{2\pi t}{\tau} + b_0'\sin\frac{2\pi t}{\tau}\right) \\
&\quad - \frac{2\pi r}{\lambda}\left(A_0'\cos\frac{2\pi t}{\tau} + B_0'\sin\frac{2\pi t}{\tau}\right) - R_\zeta
\end{aligned}\right\} \quad (28)$$

We will discuss and integrate these equations conjointly with those of the rotational motion of the ship, to the formation of which we shall pass.

§ 4. To obtain the equations of the rotational motion we must calculate explicit expressions for the moments L, M, N about the axes of the ship of all the forces acting on her. These moments consist of two parts, viz.: (1) those of the hydrodynamical support, and (2) of the resistance of water. We will denote the first by L_1, M_1, N_1, and the second by L_R, M_R, N , and we will have—

$$L_1 = \rho\int_V (y\,Z - z\,Y)\,dv; \qquad M_1 = \rho\int_V (z\,X - x\,Z)\,dv; \qquad N_1 = \rho\int_V (x\,Y - y\,X)\,dv$$

where ρ is the density of water, X, Y, Z the components of the support acting at the points (x, y, z) on unity of volume, the integration being performed over the whole submerged volume V.

We have the formula (18) for the components Ξ, H, Z of the support on fixed axes in space; to obtain X, Y, Z we have the relations :—

$$\begin{aligned}
X &= a\Xi + a_1 H + a_2 Z \\
Y &= b\Xi + b_1 H + b_2 Z \\
Z &= c\Xi + c_2 H + c_2 Z
\end{aligned}$$

Taking from the schedule (9′) the approximate values of the cosines and the expressions (18), we obtain—

$$\begin{aligned}
X &= -\frac{2\pi r}{\lambda_1} g\sin U - \frac{2\pi r}{\lambda_2} g\phi\,.\sin U + g\left(1 + \frac{2\pi r}{\lambda}\cos U\right)\psi \\
Y &= \frac{2\pi r}{\lambda_1} g\phi\sin U - \frac{2\pi r}{\lambda_2} g\sin U - g\left(1 + \frac{2\pi r}{\lambda}\cos U\right)\theta_1 \\
Z &= -\frac{2\pi r}{\lambda} g\psi\,\text{s.n}\,U + \frac{2\pi r}{\lambda_2} g\theta_1\sin U - g\left(1 + \frac{2\pi r}{\lambda}\cos U\right)
\end{aligned}$$

and remarking that $\frac{2\pi r}{\lambda_1}$, $\frac{2\pi r}{\lambda_2}$, and $\frac{2\pi r}{\lambda}$ are small quantities of the first order, we must take for our first approximation—

$$\left.\begin{aligned}
\frac{1}{g}X &= -\frac{2\pi r}{\lambda_1}\sin U + \psi \\
\frac{1}{g}Y &= -\frac{2\pi r}{\lambda_2}\sin U + \theta_1 \\
\frac{1}{g}Z &= -1 - \frac{2\pi r}{\lambda}\cos U
\end{aligned}\right\} \quad (29)$$

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then we obtain—

$$L_1 = \int_V \left[y \left(-1 - \frac{2\pi r}{\lambda} \cos U \right) + z \left(\frac{2\pi r}{\lambda_2} \sin U + \theta_1 \right) \right] dv$$
$$= -\int_V y\, dv + \theta_1 \int_V z\, dv - \frac{2\pi r}{\lambda} \int_V y \cos U\, dv + \frac{2\pi r}{\lambda_2} \int_V z \sin U\, dv \qquad (30)$$

$$M_1 = \int_V \left[z \left(\psi - \frac{2\pi r}{\lambda_1} \sin U \right) - x \left(-1 - \frac{2\pi r}{\lambda} \cos U \right) \right] dv$$
$$= \psi \int_V z\, dv + \int_V x\, dv - \frac{2\pi r}{\lambda_1} \int_V z \sin U\, dv + \frac{2\pi r}{\lambda} \int_V x \cos U\, dv \qquad (31)$$

$$N_1 = \int_V \left[x \left(-\frac{2\pi r}{\lambda_2} \sin U - \theta_1 \right) - y \left(\psi - \frac{2\pi r}{\lambda_1} \sin U \right) \right] dv$$
$$= -\theta_1 \int_V x\, dv - \psi \int_V y\, dv - \frac{2\pi r}{\lambda_2} \int_V x \sin U\, dv + \frac{2\pi r}{\lambda_1} \int_V y \sin U\, dv \qquad (32)$$

and all this is reduced to the calculation of the following eight integrals—

$$\int_V x\, dv;\ \int_V y\, dv;\ \int_V z\, dv;\ \int_V x \cos U\, dv;\ \int_V x \sin U\, dv;\ \int_V y \cos U\, dv;$$
$$\int_V y \sin U\, dv;\ \int_V z \sin U\, dv;$$

every one of which consists of two parts, the first relating to the constant volume V_0, and the second to the variable one V_t, and we see immediately that—

$$\int_{V_0} x\, dv = 0;\ \int_{V_0} y\, dv = 0;\ \text{and} \int_{V_0} z\, dv = a V_0$$

a being the distance of the centre of gravity to the centre of buoyancy. The integral $\int_V z\, dv$, entering into the formulæ, multiplied by a small factor of the first order, the part of it relating to the volume V_t will only give terms of the second order, which we need not calculate now; for the other two, $\int_{V_t} x\, dv$ and $\int_{V_t} y\, dv$, we obtain, in accordance with formula (24).

$$\int_{V_t} x\, dv = -\int_{-L}^{+L} x\, dx \int_{-y_0}^{+y_0} (-\zeta_0 + x\psi - y\theta_1)\, dy - r \int_{-L}^{+L} x\, dx \int_{-y_0}^{+y_0} \cos 2\pi \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau} \right) dy$$
$$= \zeta_0 S l - \psi \dot{I}_0 - r \left(a_1' \cos \frac{2\pi t}{\tau} + b_1' \sin \frac{2\pi t}{\tau} \right) \qquad (33)$$

where $\dot{I}_0 = 2 \int_{-L}^{+L} x^2 y_0\, dx$ is the moment of inertia of the area of the L.W.L. about the transverse axis, and—

$$a_1' = \frac{\lambda_2}{\pi} \int_{-L}^{+L} x \cdot \sin \frac{2\pi y_0}{\lambda_2} \cos \frac{2\pi x}{\lambda_1}\, dx; \qquad b_1' = \frac{\lambda_2}{\pi} \int_{-L}^{+L} x \cdot \sin \frac{2\pi y_0}{\lambda_2} \sin \frac{2\pi x}{\lambda_1}\, dx \qquad (33')$$

and in the same manner—

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$$\int_v y\,d\,v = -\int_{-L}^{+L} d\,x \int_{-y_0}^{+y_0} (-\zeta_0 + x\,\psi - \theta_1)\,y\,d\,y - r\int_{-L}^{+L} d\,x \int_{-y_0}^{+y_0} y \cos 2\pi\left(\frac{x}{\lambda_1} + \frac{y\,t}{\lambda_2\,\tau}\right) d\,y$$

$$= \frac{2}{3}\theta_1 \int_{-L}^{+L} y_0^3\,d\,x - r\frac{\lambda_2}{\pi}\int_{-L}^{+L}\left(y_0 \cos\frac{2\pi\,y_0}{\lambda_2} - \frac{\lambda_2}{2\pi}\sin\frac{2\pi\,y_0}{\lambda_2}\right)\sin 2\pi\left(\frac{x}{\lambda_1} - \frac{t}{\tau}\right) d\,x$$

$$= \theta_1\,K_0 - r\left[\left(d_1' - \frac{\lambda_2}{2\pi}\,b_0'\right)\cos\frac{2\pi\,t}{\tau} - \left(c_1' - \frac{\lambda_2}{2\pi}\,a_0'\right)\sin\frac{2\pi\,t}{\tau}\right] \qquad (34)$$

where we put—

$K_0 = \frac{2}{3}\int_{-L}^{+L} y_0^3\,d\,x$ = the moment of inertia of the L.W.L. about the longitudinal axis, and—

$$c_1' = \frac{\lambda_2}{\pi}\int_{-L}^{+L} y_0 \cos\frac{2\pi\,y_0}{\lambda_2}\cos\frac{2\pi\,x}{\lambda_1}\,d\,x\,; \qquad d_1' = \int_{-L}^{+L} y_0 \cos\frac{2\pi}{\lambda_2}\,y_0 \sin\frac{2\pi\,x}{\lambda_1}\,d\,x \qquad (34')$$

a'_0 and b_0' having the values (26).

All the other integrals like $\int_v x\cos U\,d\,v$ are multiplied by one of the small factors $\frac{2\pi\,r}{\lambda}$, $\frac{2\pi\,r}{\lambda_1}$, $\frac{2\pi\,r}{\lambda_2}$ and therefore we need only to calculate the parts of them relating to V_0, and the argument U can be taken equal to $2\pi\left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau}\right)$ as above. We then obtain—

$$\int_{v_0} x\cos U\,d\,v = \int_0^h d\,z\int_{-L}^{+L} x\,d\,x\int_{-y}^{+y}\cos 2\pi\left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau}\right) d\,y$$

$$= \frac{\lambda_2}{\pi}\int_0^h d\,z\int_{-L}^{+L} x.\sin\frac{2\pi\,y}{\lambda_2}\cos 2\pi\left(\frac{x}{\lambda_1} - \frac{t}{\tau}\right) d\,x$$

$$= A_1'\cos\frac{2\pi\,t}{\tau} + B_1'\sin\frac{2\pi\,t}{\tau} \qquad (35)$$

$$\int_{v_0} x\sin U\,d\,v = \int_0^h d\,z\int_{-L}^{+L} x\,d\,x\int_{-y}^{+y}\sin 2\pi\left(\frac{x}{\lambda_1} + \frac{y}{\lambda} - \frac{t}{\tau}\right) d\,y$$

$$= \frac{\lambda_2}{\pi}\int_0^h d\,z\int_{-L}^{+L} x\sin\frac{2\pi\,y}{\lambda_2}\sin 2\pi\left(\frac{x}{\lambda_1} - \frac{t}{\tau}\right) d\,x = B_1'\cos\frac{2\pi\,t}{\tau} - A_1'\sin\frac{2\pi\,t}{\tau} \qquad (36)$$

$$\int_{v_0} y\cos U\,d\,v = \int_0^h d\,z\int_{-L}^{+L} d\,x\int_{-y}^{+y} y\cos 2\pi\left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau}\right) d\,y$$

$$= \frac{\lambda_2}{\pi}\int_0^h d\,z\int_{-L}^{+L}\left[y\cos\frac{2\pi\,y}{\lambda_2} - \frac{\lambda_2}{\pi}\sin\frac{2\pi\,y}{\lambda_2}\right]\sin 2\pi\left(\frac{x}{\lambda_1} - \frac{t}{\tau}\right) d\,x$$

$$= \left(D_1' - \frac{\lambda_2}{2\pi}\,B_0'\right)\cos\frac{2\pi\,t}{\tau} - \left(C_1' - \frac{\lambda_2}{2\pi}\,A_0'\right)\sin\frac{2\pi\,t}{\tau} \qquad (37)$$

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$$\int_{r_0} y \sin U \, dv = \int_0^h dz \int_{-L}^{+L} dx \int^{+y} y \sin 2\pi \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau}\right) dy$$

$$= -\frac{\lambda_2}{\pi} \int_0^h dz \int_{-L}^{+L} \left[y \cos \frac{2\pi y}{\lambda_2} - \frac{\lambda_2}{2\pi} \sin \frac{2\pi y}{\lambda_2} \right] \cos 2\pi \left(\frac{x}{\lambda_1} - \frac{t}{\tau}\right) dx$$

$$= -\left[\left(C_1' - \frac{\lambda_2}{2\pi} A_0' \right) \cos \frac{2\pi t}{\tau} + \left(D_1' - \frac{\lambda_2}{2\pi} B_0' \right) \sin \frac{2\pi t}{\tau} \right] \qquad (38)$$

$$\int_{r_0} z \sin U \, dv = \int_0^h z \, dz \int_{-L}^{+L} dx \int_{-y}^{+y} \sin 2\pi \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau}\right) dy$$

$$= \frac{\lambda_2}{\pi} \int_0^h dz \int_{-L}^{+L} \sin \frac{2\pi y}{\lambda_2} \sin 2\pi \left(\frac{x}{\lambda_1} - \frac{t}{\tau}\right) dx = F_1' \cos \frac{2\pi t}{\tau} - E_1' \sin \frac{2\pi t}{\tau} \qquad (39)$$

where y denotes the ordinate of the surface of the ship corresponding to the values x and z of the other two co-ordinates, and is to be taken from the body's plane. The constant parameters A_1', B_1', &c., have the values given by the schedule (40), in which they are all recapitulated for an easier glance: —

$$a_0' = \frac{\lambda_2}{\pi} \int_{-L}^{+L} \sin \frac{2\pi y_0}{\lambda_2} \cos \frac{2\pi x}{\lambda_1} dx; \qquad b_0' = \frac{\lambda_2}{\pi} \int_{-L}^{+L} \sin \frac{2\pi y_0}{\lambda_2} \sin \frac{2\pi x}{\lambda_1} dx$$

$$a_1' = \frac{\lambda_2}{\pi} \int_{-L}^{+L} x \sin \frac{2\pi y_0}{\lambda_2} \cos \frac{2\pi x}{\lambda_1} dx; \qquad b_1' = \frac{\lambda_2}{\pi} \int_{-L}^{+L} x \sin \frac{2\pi y_0}{\lambda_2} \sin \frac{2\pi x}{\lambda_1} dx$$

$$c_1' = \frac{\lambda_2}{\pi} \int_{-L}^{+L} y_0 \cos \frac{2\pi y_0}{\lambda_2} \cos \frac{2\pi x}{\lambda_1} dx; \qquad d_1' = \frac{\lambda_2}{\pi} \int_{-L}^{+L} y_0 \cos \frac{2\pi y_0}{\lambda_2} \sin \frac{2\pi x}{\lambda_1} dx$$

$$S = 2 \int_{-L}^{+L} y_0 \, dx; \quad Sl = 2 \int_{-L}^{+L} x y_0 \, dx; \qquad I_0 = V_0 R_0 = 2 \int_{-L}^{+L} x^2 y_0 \, dx; \quad K_0 = V_0 r_0 = \frac{2}{3} \int_{-L}^{+L} y_0^3 \, dx$$

$$A_0' = \frac{\lambda_2}{\pi} \int_0^h \int_{-L}^{+L} \sin \frac{2\pi y}{\lambda_2} \cos \frac{2\pi x}{\lambda_1} dx \, dz; \qquad B_0' = \frac{\lambda_2}{\pi} \int_0^h \int_{-L}^{+L} \sin \frac{2\pi y}{\lambda_2} \sin \frac{2\pi x}{\lambda_1} dx \, dz \qquad (40)$$

$$A_1' = \frac{\lambda_2}{\pi} \int_0^h \int_{-L}^{+L} x \sin \frac{2\pi y}{\lambda_2} \cos \frac{2\pi x}{\lambda_1} dx \, dz; \qquad B_1' = \frac{\lambda_2}{\pi} \int_0^h \int_{-L}^{+L} x \sin \frac{2\pi y}{\lambda_2} \sin \frac{2\pi x}{\lambda_1} dx \, dz$$

$$C_1' = \frac{\lambda_2}{\pi} \int_0^h \int_{-L}^{+L} y \cos \frac{2\pi y}{\lambda_2} \cos \frac{2\pi x}{\lambda_1} dx \, dz; \qquad D_1' = \frac{\lambda_2}{\pi} \int_0^h \int_{-L}^{+L} y \cos \frac{2\pi y}{\lambda_2} \sin \frac{2\pi x}{\lambda_1} dx \, dz$$

$$E_1' = \frac{\lambda_2}{\pi} \int_0^h \int_{-L}^{+L} z \sin \frac{2\pi y}{\lambda_2} \cos \frac{2\pi x}{\lambda_1} dx \, dz; \qquad F_1' = \frac{\lambda_2}{\pi} \int_0^h \int_{-L}^{+L} z \sin \frac{2\pi y}{\lambda_2} \sin \frac{2\pi x}{\lambda_1} dx \, dz$$

$$V_0 = 2 \int_0^h \int_{-L}^{+L} y \, dx \, dz; \qquad a V_0 = 2 \int_0^h \int_{-L}^{+L} z y \, dx \, dz$$

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All the simple integrals relate to the load-water line of which y_0 is the ordinate corresponding to the abscissa x, the double integrals relate to the whole displacement V_0 of the ship, and y is the ordinate of that point of her surface, of which the other two co-ordinates are x and z.*

On substituting the expressions (33, 34 . . . . 39) in those of the moments L_1, M_1, N_1, we obtain the following equations of the motion of the ship :—

$$\left.\begin{aligned}
A\frac{d^2\theta_1}{dt^2} &= g\rho\Big[-\theta_1(K_0 - aV_0) + r\Big(h_1'\cos\frac{2\pi t}{\tau} - g_1'\sin\frac{2\pi t}{\tau}\Big) - \frac{2\pi r}{\lambda}\Big(H_1'\cos\frac{2\pi t}{\tau} - G_1'\sin\frac{2\pi t}{\tau}\Big)\\
&\quad + \frac{2\pi r}{\lambda_2}\Big(F_1'\cos\frac{2\pi t}{\tau} - E_1'\sin\frac{2\pi t}{\tau}\Big)\Big] - L_R \quad \ldots\ldots\ldots \text{(rolling)}\\
B\frac{d^2\psi}{dt^2} &= g\rho\Big[-\psi(I_0 - aV_0) + \zeta_0 S l - r\Big(a_1'\cos\frac{2\pi t}{\tau} + b_1'\sin\frac{2\pi t}{\tau}\Big) - \frac{2\pi r}{\lambda_1}\Big(F_1'\cos\frac{2\pi t}{\tau} - E_1'\sin\frac{2\pi t}{\tau}\Big)\\
&\quad + \frac{2\pi r}{\lambda}\Big(A_1'\cos\frac{2\pi t}{\tau} + B_1'\sin\frac{2\pi t}{\tau}\Big)\Big] - M_R \quad \ldots\ldots\ldots \text{(pitching)}\\
C\frac{d^2\phi}{dt^2} &= -g\rho\Big[\frac{2\pi r}{\lambda_1}\Big(G_1'\cos\frac{2\pi t}{\tau} + H_1'\sin\frac{2\pi t}{\tau}\Big) + \frac{2\pi r}{\lambda_2}\Big(A_1'\cos\frac{2\pi t}{\tau} + B_1'\sin\frac{2\pi t}{\tau}\Big)\Big] - N_R \text{ (yawing)}
\end{aligned}\right\} \quad (41)$$

Here g_1', h_1', G_1', H_1' denote the following combinations—

$$\left.\begin{aligned}
g_1' &= c_1' - \frac{\lambda}{2\pi}a_0'; \qquad h_1' = d_1' - \frac{\lambda_2}{2\pi}b_0'\\
G_1' &= C_1' - \frac{\lambda_2}{2\pi}A_0'; \qquad H_1' = D_1' - \frac{\lambda_2}{2\pi}B_0'
\end{aligned}\right\} \quad (40')$$

The equation (41) will take a more condensed form, if we remark that the greatest wave slope Θ_0 is given by the relation $\sin\Theta_0 = \frac{2\pi r}{\lambda}$, or simply $\Theta^0 = \frac{2\pi r}{\lambda}$, as Θ_0 does not exceed 9^0, and that the weight of the ship $P = g\rho V_0$, V_0 being the displacement of the ship ; and if we put—

$$\left.\begin{aligned}
M_1' &= \frac{1}{V_0(r_0 - a)}\Big[E_1' - \frac{\lambda_2}{\lambda}G_1' + \frac{\lambda_2}{2\pi}g_1'\Big]; \qquad N_1' = \frac{1}{V_0(r_0 - a)}\Big[F_1' - \frac{\lambda_2}{\lambda}H_1' + \frac{\lambda_2}{2\pi}h_1'\Big]\\
K_1' &= \frac{1}{V_0(R_0 - a)}\Big[\frac{\lambda_1}{\lambda}A_1' - F_1' - \frac{\lambda_1}{2\pi}a_1'\Big]; \qquad L_1' = \frac{1}{V_0(R_0 - a)}\Big[\frac{\lambda_1}{\lambda}B_1' - E_1' - \frac{\lambda_1}{2\pi}b_1'\Big]\\
P_1' &= \frac{1}{V_0}\Big[G_1'\cos a + B_1'\sin a\Big]; \qquad Q_1' = \Big[H_1'\cos a + A_1'\sin a\Big]\cdot\frac{1}{V_0}
\end{aligned}\right\} \quad (42)$$

the equations (41) will be—

$$\left.\begin{aligned}
A\frac{d^2\theta_1}{dt^2} + P(r_0 - a)\theta_1 &= P(r_0 - a)\Theta_0\sin a\Big(N_1'\cos\frac{2\pi t}{\tau} - M_1'\sin\frac{2\pi t}{\tau}\Big) - L_R\\
B\frac{d^2\psi}{dt^2} + P(R_0 - a)\psi &= P(R_0 - a)\Theta_0\cos a\Big(K_1'\cos\frac{2\pi t}{\tau} + L_1'\sin\frac{2\pi t}{\tau}\Big) + g\rho S l\zeta_0 - M_R\\
\frac{C}{d}\frac{d^2}{t^2}\phi &= -P\Theta_0\Big(P_1'\cos\frac{2\pi t}{\tau} + Q_1'\sin\frac{2\pi t}{\tau}\Big) - N_R
\end{aligned}\right\} \quad (41')$$

* It may be remarked here that if we would consider, in the second approximation, the gradual decrease of radius of the generating circle with the depth, in all the double integrals, which are multiplied by one of the factors $\frac{2\pi r}{\lambda}$, $\frac{2\pi r}{\lambda_1}$, $\frac{2\pi r}{\lambda_2}$, dz should be replaced by $e^{-\frac{2\pi z}{\lambda}}dz$. This remark must be taken into account especially for the calculation of rolling, and it is convenient to introduce the reduction factor $e^{-\frac{2\pi z}{\lambda}}$ even for the first approximation, as will be shown in the numerical example.

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where A, B, C, are the principal moments of inertia of the ship, P her weight; r_0 the transverse, and R_0 the longitudinal metacentrical radii, L_R M_R, N_R, the moments of resistance of the water to the oscillations of the ship.

§ 5. We shall discuss these equations on a numerical example treated with all the details, and there we will show their applications to the study of the nautical qualities of a ship, but we shall consider first some particular cases, which will serve us as an illustration of our method. In the first instance we will make the hypothesis of Mr. W. Froude, that the dimensions of the ship are very small if compared with those of the wave, and we will deduce his equation for the rolling from the first of ours (41′). When the ship steams in the trough of the sea (parallel to the crests of waves) her head angle α in our notation is 90° when the waves come from the starboard side, and is 270° when the waves come from port side, but for this last case we can also change θ_1 into $-\theta_1$, and consider only the first one. Then we have :—

$$\lambda_1 = \frac{\lambda}{\cos \alpha} = \frac{\lambda}{\cos 90^\circ} = \infty \; ; \qquad \lambda_2 = \frac{\lambda}{\sin \alpha} = \frac{\lambda}{\sin 90^\circ} = \lambda.$$

And at the same time, the dimensions of the ship being very small, the quantity $\frac{2\pi y}{\lambda}$ will be a small one, and $\sin \frac{2\pi y}{\lambda}$ can be replaced by $\frac{2\pi y}{\lambda}$ in all the formulæ (33)—(38); and, remarking that —

$$\cos \frac{2\pi x}{\lambda_1} = 1, \qquad \sin \frac{2\pi x}{\lambda_1} = 0,$$

we obtain from the schedule (40) in this case—

$$A_0' = 2\int_0^h \int_{-L}^{+L} y \, dz \, dx = V_0$$

$$B_0' = b_0' = b_1' = d_1' = B_1' = D_1' = F_1' = 0.$$

But it would be an error to conclude that $g_1' = 0$, as it seems when in the expressions for a_0' and c_1', $\sin \frac{2\pi y}{\lambda}$ and $\cos \frac{2\pi y}{\lambda}$ are replaced by $\frac{2\pi y}{\lambda}$ and 1. Indeed, the parameter g_1' proceeds from the evaluation of the integral—

$$\int_{-L}^{+L} dx \int_{-y_0}^{+y_0} y \cos 2\pi \left(\frac{x}{\lambda_1} + \frac{y}{\lambda_2} - \frac{t}{\tau} \right) dy$$

which (as $\lambda_1 = \infty$) will be—

$$\int_{-L}^{+L} dx \int_{-y_0}^{+y_0} y \cos 2\pi \left(\frac{y}{\lambda} - \frac{t}{\tau} \right) dy = \cos \frac{2\pi t}{\tau} \cdot \int_{-L}^{+L} dx \int_{-y_0}^{+y_0} y \cos \frac{2\pi y}{\lambda} \, dy + \sin \frac{2\pi t}{\tau} \cdot \int_{-L}^{+L} dx \int_{-y_0}^{+y_0} y \sin \frac{2\pi y}{\lambda} \, dy$$

The first of the integrals of the left-hand members is equal to zero, and the second, after the above-said substitutions, will be—

$$\int_{-L}^{+L} dx \int_{-y}^{+y_0} \frac{2\pi}{\lambda} y^2 \, dy = \frac{2\pi}{\lambda} \cdot \frac{2}{3} \int_{-L}^{+L} y^3 \, dx = \frac{2\pi}{\lambda} K_0$$

and, comparing this with the form (34), we see that the value of g_1' in this case is—

$$g_1' = -\frac{2\pi}{\lambda} K_0 = -\frac{2\pi}{\lambda} \cdot r_0 V_0$$

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This same value will also be obtained if, in the expressions c_1' and a_0', $\sin \frac{2\pi y}{\lambda}$, and $\cos \frac{2\pi y}{\lambda}$ be respectively replaced by the first two terms of their developments—

$$\frac{2\pi y}{\lambda} - \frac{1}{6} \cdot \left(\frac{2\pi y}{\lambda}\right)^3 \text{ and } 1 - \frac{1}{2} \cdot \left(\frac{2\pi y}{\lambda}\right)^2.$$

It is the presence of the factor $\frac{\lambda}{2\pi}$ in the expression of—

$$g_1' = c_1' - \frac{\lambda}{2\pi} a_0'$$

which necessitates the consideration of these terms.

It will be found quite in the same manner that—

$$G_1' = -\frac{4}{3}\frac{\pi}{\lambda} \int_0^h dz \int_{-L}^{+L} y^3 \, dx.$$

It is obvious that, if, instead of y, we take the corresponding ordinate of the L.W.L. y_0, we obtain a greater value of the integral in the right-hand term of the above equation, and thus the absolute value of G_1'

$$G_1' < \frac{2\pi h}{\lambda} K_0$$

where—

$$K_0 = \frac{2}{3} \int_{-L}^{+L} y_0^3 \, dx$$

The value of E_1' will be—

$$E' = 2 \int_0^h z \, dz \int_{-L}^{+L} y \, dx = a V_0$$

and thus—

$$M_1' = \frac{1}{V_0 (r_0 - a)} \cdot \left[E_1' - \frac{\lambda_2}{\lambda} G_1' + \frac{\lambda_2}{2\pi} g_1' \right]$$

$$= \frac{1}{V_0 (r_0 - a)} \left[a V_0 - r_0 V_0 + G_1' \right] = -1 - \frac{G_1'}{V_0 (r_0 - a)}$$

But the value of the term—

$$-\frac{G_1'}{V_0 (r_0 - a)} < \frac{2\pi h}{\lambda} \cdot \frac{V_0 a}{V_0 (r_0 - a)}$$

or—

$$-\frac{G_1'}{V_0 (r_0 - a)} < \frac{2\pi h}{\lambda} \cdot \frac{a}{r_0 - a}.$$

According to the hypothesis of Froude the ratio $\frac{h}{\lambda}$ is infinitely small, thus—

$$\frac{G'}{V_0 (r_0 - a)}$$

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is very small, and can be neglected in comparison with -1; and therefore for Froude's case $M_1' = -1$, and equation (41') will be—

$$A \frac{d^2 \theta_1}{d t^2} + P (r_0 - a) \theta_1 = P (r_0 - a) \Theta_0 \sin \frac{2 \pi t}{\tau} \qquad (43)$$

the well-known equation of Froude for the unresisted rolling, for which case $L = 0$.

If we make in our formulæ $a = 90°$, but do not make the hypothesis that the dimensions of the ship are infinitely small as compared with those of the wave, we obtain an analytical expression for M. Bertin's reduction co-efficients. This expression furnishes a very simple manner of the calculation of this co-efficient.

Indeed, in this case, we have, as before :—

$$b_0' = b_1' = d_1' = B_0' = B_1' = D_1' = F_1' = 0$$

thus—

$$N_1' = 0 \quad \text{and} \quad M_1' = \left[E_1' - G_1' + \frac{\lambda}{2 \pi} g_1 \right] \frac{1}{V_0 (r_0 - a)}$$

which is the required expression for M. Bertin's co-efficient, or better, of the product of the three co-efficients. We will give some remarks on this subject in our numerical calculations.

Mr. W. Froude allows, in his theory of rolling, that the centre of gravity of the ship describes in space uniformly the same circular orbit as the particles of water. We will show that this result is an immediate consequence of our equation (28).

Mr. W. Froude considered the unresisted rolling, for which case the equations (28) become—

$$\left.\begin{aligned} \frac{V_0}{g} \cdot \frac{d^2 \xi_0}{d t^2} &= 0 \\ \frac{V_0}{g} \cdot \frac{d^2 \eta_0}{d t^2} &= V_0 \cdot \frac{2 \pi r}{\lambda} \cdot \sin \frac{2 \pi t}{\tau} \\ \frac{V_0}{g} \cdot \frac{d^2 \zeta_0}{d t^2} + S \cdot \zeta_0 &= S l \psi + r S \cos \frac{2 \pi t}{\tau} - \frac{2 \pi r}{\lambda} V_0 \cos \frac{2 \pi t}{\tau} \end{aligned}\right\} \qquad (28')$$

But, as there is no pitching, $\psi = 0$, and the first two equations give—

$$\xi_0 = C_1 + C_2 t$$

$$\eta_0 = C_3 + C_4 t - \frac{r^2 g}{2 \pi} \frac{r}{\lambda} \sin \frac{2 \pi t}{\tau}$$

where C_1, C_2, C_3, C_4 are arbitrary constants of integration. Putting—

$$\frac{S \cdot g}{V_0} = n_2$$

in the last equation, and remarking that $\frac{2 \pi r}{\lambda} V_0$ is a very small quantity in comparison with $r S$, because $V_0 < S h$, thus—

$$\frac{2 \pi r V_0}{\lambda} < S r \cdot \frac{h}{\left(\frac{\lambda}{2 \pi}\right)},$$

and the ratio $\frac{h}{\left(\frac{\lambda}{2 \pi}\right)}$ of the draught of the ship to the radius of the rolling circle being by Froude's

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hypothesis infinitely small, the third equation (28′) will be—

$$\frac{d^2 \zeta_0}{d t^2} + n^2 \zeta_0 = r\, n^2 \cos \frac{2 \pi t}{\tau}$$

and its integral—

$$\zeta_0 = C_5 \cos n t + C_6 \sin n t + \frac{r n^2}{n^2 - \frac{4 \pi^2}{\tau^2}} \cos \frac{2 \pi t}{\tau}$$

where C_5, C_6 are two arbitrary constants.

It can be easily concluded that the values of the constants C_1, C_2, C_3, C_4 are zero; if the initial conditions are such that C_5 and C_6 are also zero,* then we should have—

$$\xi_0 = 0; \qquad \eta_0 = -\frac{g \tau^2}{2 \pi \lambda} . r \sin \frac{2 \pi t}{\tau}; \qquad \zeta_0 = r . \frac{n^2}{n^2 - \frac{4 \pi^2}{\tau^2}} \cos \frac{2 \pi t}{\tau}$$

If we put $n = \frac{2 \pi}{T}$, then $T = 2 \pi \sqrt{\frac{V_0}{S g}}$,

and, as

$$V_0 < S h, \quad T < 2 \pi \sqrt{\frac{h}{g}}.$$

By the properties of trochoidal waves we have the following relation between their period τ and length λ :—

$$\tau = \sqrt{\frac{2 \pi \lambda}{g}},$$

thus :—

$$\xi_0 = 0; \qquad \eta_0 = - r \sin \frac{2 \pi t}{\tau}; \qquad \zeta_0 = r . \frac{\tau^2}{\tau^2 - T^2} \cos \frac{2 \pi t}{\tau}.$$

The ratio $\frac{T}{\tau} < \sqrt{\frac{2 \pi h}{\lambda}}$ is, in the hypothesis of Froude, a very small one; then the fraction

$$\frac{\tau^2}{\tau^2 - T^2} = \frac{1}{1 - \frac{T^2}{\tau^2}}$$

is very near to 1, and the equations of the motion of the centre of gravity of the ship would be—

$$\xi_0 = 0; \qquad \eta_0 = - r \sin \frac{2 \pi t}{\tau}; \qquad \zeta_0 = r \cos \frac{2 \pi t}{\tau} \qquad (44)$$

which show that this point moves quite in the same manner as the particles of water, as is admitted by Mr. W. Froude. We see thus that this admission is not an independent hypothesis, but an immediate consequence of the other hypotheses relating to the wave support.

§ 6. On putting in formulæ (40) and (41) $a = 0$, we obtain the equations of the pitching motion, which are given in my previous paper, for the case when the ship steams in the direction of the flow of the waves, and $a = 180°$ corresponds to the case when the ship steams against the waves.

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* If resistance be taken into account, the terms containing C_5 and C_6 extinguish gradually, and there remain only the forced oscillations, which are almost independent of the resistance; thus C_5 and C_6 can practically always be supposed zero.

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§ 7. The general formulæ (40) can, in most cases of practice, be replaced by simpler ones. This very usual case is when the breadth of the ship is relatively small as compared with the length of the wave, so that $\sin \frac{2\pi y}{\lambda_2}$ can be simply replaced by $\frac{2\pi y}{\lambda_2}$, and all the other terms of its development can be neglected, and $\cos \frac{2\pi y}{\lambda_2}$ can be replaced by the first two terms of its development—

$$1 - \frac{1}{2} \cdot \left(\frac{2\pi y}{\lambda_2}\right)^2.$$

In this case the constants given by the schedule (40) will have the following expressions :—

$$\left.\begin{aligned}
a_0' &= 2\int_{-L}^{+L} y_0 \cos\frac{2\pi x}{\lambda_1}\,dx; & b_0' &= 2\int_{-L}^{+L} y_0 \sin\frac{2\pi x}{\lambda_1}\,dx \\
a_1' &= 2\int_{-L}^{+L} y_0 x \cos\frac{2\pi x}{\lambda_1}\,dx; & b_1' &= 2\int_{-L}^{+L} y_0 x \sin\frac{2\pi x}{\lambda_1}\,dx \\
A_0' &= 2\int_{-L}^{+L}\int_{0}^{h} y \cos\frac{2\pi x}{\lambda_1}\,dx\,dz; & B_0' &= 2\int_{-L}^{+L}\int_{0}^{h} y \sin\frac{2\pi x}{\lambda_1}\,dx\,dz \\
E_1' &= 2\int_{-L}^{+L}\int_{0}^{h} y\,z \cos\frac{2\pi x}{\lambda_1}\,dx\,dz; & F_1' &= 2\int_{-L}^{+L}\int_{0}^{h} y\,z \sin\frac{2\pi x}{\lambda_1}\,dx\,dz \\
g_1' &= -\frac{4\pi}{3\lambda_2}\int_{-L}^{+L} y_0^3 \cos\frac{2\pi x}{\lambda_1}\,dx; & h_1' &= -\frac{4\pi}{3\lambda_2}\int_{-L}^{+L} y_0^3 \sin\frac{2\pi x}{\lambda_1}\,dx \\
G_1' &= -\frac{4\pi}{3\lambda_2}\int_{-L}^{+L}\int_{0}^{h} y^3 \cos\frac{2\pi x}{\lambda_1}\,dx\,dz; & H_1' &= -\frac{4\pi}{3\lambda_2}\int_{-L}^{+L}\int_{0}^{h} y^3 \sin\frac{2\pi x}{\lambda_1}\,dx\,dz
\end{aligned}\right\} \quad (40')$$

And, as has been remarked about the formula (40), it must be repeated here that, if we had considered the structure of the trochoidal wave, and taken into account the progressive diminution of the generating radii, in all the double integrals, such as A_0', B_0', E_1', F_1', G_1', H_1', we would have the factor $e^{-\frac{2\pi z}{\lambda}}$.

In our numerical example we shall use these formulæ (40').

§ 8. For this example we take the same ship, *Amiral Korniloff*, as for the calculation of pitching (Trans. I.N.A. Vol. XXXVII., p. 347). The calculation will be made with all the details for the angle $\alpha = 45°$, and the final results, only, will be given for all the other values of this angle. These calculations will show that, when properly arranged, they are far from being so complicated as may seem at first.

The dimensions of the ship are as follow—

Length	$2L$	= 107 metres.
Beam	$2B$	= 14·8 ,,
Draught	h	= 5·9 ,,
Displacement	V_0	= 5,000 metric tons.

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The elements of the wave—

Length	...	...	...	...	...	...	...	$\lambda = 125$ metres.
Height	...	...	...	...	...	...	...	$2r = 5$,,
Period	...	...	...	...	...	...	...	$\tau = 9$ seconds.

To see if the formulæ (40′) are applicable, or not, for all the values of the head angle a, we must calculate the greatest value of $\frac{2\pi y}{\lambda_2}$; the least value of λ_2 is λ, and the greatest value of y is B, thus—

$$\frac{2\pi y}{\lambda_2} \leq 2\pi . \frac{7.4}{125}, \quad \text{or} \quad \frac{2\pi y}{\lambda_2} \leq 21^\circ = 0{\cdot}366.$$

Then we have—

$$\sin 21^\circ = 0{\cdot}358, \text{ and } \cos 21^\circ = 0{\cdot}934, \text{ and } 1 - \frac{1}{2}(0{\cdot}366)^2 = 0{\cdot}932;$$

thus, with a relative error less than 2 per cent., we can take—

$$\sin \frac{2\pi y}{\lambda_2} = \frac{2\pi y}{\lambda_2},$$

the exactitude of the formula—

$$\cos \frac{2\pi y}{\lambda_2} = 1 - \frac{1}{2} \cdot \left(\frac{2\pi y}{\lambda_2}\right)^2$$

is nearly $\frac{2}{10}$ per cent., hence we can use the formulæ (40′), for all the values of a.

The Tchebyscheff's rule for the quadratures is to be used. This rule and its application to shipbuilders' calculation is fully explained in my paper, "Nouvelle Méthode de Calcul des Elements d'une Carène," Bull. de l'Assn. Technique Maritime, No. iv., or Pollard et Dudebout "Théorie du Navire," Tome iv.

HEAD ANGLE $a = 45^\circ$.

Data—

$$L = 53{\cdot}5 \text{ m.}; \quad h = 5{\cdot}9 \text{ m.}; \quad \lambda = 125 \text{ m.}; \quad r = 2{\cdot}5 \text{ m.}$$

$$\lambda_1 = \frac{\lambda}{\cos a} = 176{\cdot}7 \text{ m.}; \quad \lambda_2 = \frac{\lambda}{\sin a} = 176{\cdot}7 \text{ m.}$$

$$2\pi \frac{x}{\lambda_1} = 180^\circ . \frac{x}{L} . \frac{2L}{\lambda_1} \ldots . \quad \text{(absolute value).}$$

No. of the Section.	$\frac{x}{L}$	$\frac{2\pi x}{\lambda_1}$	$\cos \frac{2\pi x}{\lambda_1}$	$\sin \frac{2\pi x}{\lambda_1}$
1 & 7	0·884	96·3°	− 0·110	0·994
2 & 6	0·530	57·8°	0·532	0·846
3 & 5	0·324	35·3°	0·816	0·578
4	0	0	1·000	0·000

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CALCULATION OF a_0'; b_0', a_1', b_1', S, I_0, K_0; g_1' AND h_1'

Formulæ—

$$a_0' = 2\int_{-L}^{+L} y_0 \cos\frac{2\pi x}{\lambda_1}\,dx; \qquad b_0' = 2\int_{-L}^{+L} y_0 \sin\frac{2\pi x}{\lambda_1}\,dx$$

$$a_1' = 2\int_{-L}^{+L} y_0 . x . \cos\frac{2\pi x}{\lambda_1}\,dx; \qquad b_1' = 2\int_{-L}^{+L} y_0 x \sin\frac{2\pi x}{\lambda_1}\,x\,d$$

$$S = 2\int_{-L}^{+L} y_0\,dx; \quad K_0 = \frac{2}{3}\int_{-L}^{+L} y_0^3\,dx; \qquad I_0 = \int_{-L}^{+L} y_0' . x^2\,dx; \quad Sl = \int_{-L}^{+L} y_0 x\,dx.$$

$$g_1' = -\frac{4\pi}{3\lambda_2}\int_{-L}^{+L} y_0^3 \cos\frac{2\pi x}{\lambda_1}\,dx; \qquad h_1' = -\frac{4\pi}{3\lambda_2}\int_{-L}^{+L} y_0^3 \sin\frac{2\pi x}{\lambda_1}\,dx.$$

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.
No. of the Sections.	Abscissæ x in metres.	Ordinates of the L.W.L. in mm. from drawing.	Ordinates of L.W.L. Stern part.	III. + IV.	III. − IV.	$\phi = \frac{2\pi x}{\lambda_1} = 360^\circ . \frac{x}{\lambda_1}$	V. cos ϕ	V. sin ϕ	VI. cos ϕ	VI. sin ϕ	X. x.	IX. x.	$\frac{x^2}{100}$	V. $\frac{x^2}{100}$	$\frac{y_0^3}{1000}$	XVI. cos ϕ	XVI. sin ϕ	VI. x.
1	47·3	20	36	56	−16	96·3°	− 6·2	55·7	+ 1·6	−15·8	+ 76	2640	22·37	1250	8	−1	8	−752
2	28·4	82	102	184	−20	57·8	+ 98·0	155·7	−10·6	−16·9	−301	4420	8·07	1485	551	293	466	−568
3	17·3	102	110	212	− 8	35·3	+ 73·2	122·5	− 6·5	− 4·6	−112	2120	3·00	636	1061	865	613	−138
4	0	111		111		0	+111·0	0	111		0	0	0	0	1368	1368	0	0
5	−17·3	110													1331	1085	−770	
6	−28·4	102													1061	565	−896	
7	−47·3	36													47	−5	− 47	
Sums		563					+382·2				+ 76	+9180		3371	5427	4176	+1087	−1458
							− 6·2			−373	−413					−6	−1713	
							+376			−373	−337	9180		3371	5427	4170	− 626	−1458

$S = 563 \times 2{\cdot}04 = 1{,}149.$

$a_0' = 376 \times 2{\cdot}04 = 767.$ $\qquad b_0' = -37 \times 2{\cdot}04 = -75.$ $\qquad I_0 = 337{,}100 \times 2{\cdot}04 = 675{,}500.$

$a_1' = -337 \times 2{\cdot}04 = -687.$ $\qquad b_1' = 9{,}180 \times 2{\cdot}04 = 18{,}730.$ $\qquad K_0 = \frac{1}{3} . 5{,}427 \times 9{\cdot}06 = 16{,}400$

$Sl = -1{,}458 \times 2{\cdot}04 = -2{,}970;$ $\quad -\frac{3\lambda_2}{4\pi} g_1' = 4{,}170 \times 9{\cdot}06 = 37{,}800;$ $\quad -\frac{3\lambda_2}{2\pi} h_1' = -626 \times 9{\cdot}06 = -5{,}670.$

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The numerical factor 2·04, by which all the sums are to be multiplied in order to obtain the corresponding values of the integrals, is the product of the following ones: $2{\cdot}04 = 2 \times \frac{1}{7} \times \frac{107}{15}$, where 107 is the length of the ship, 7 is the number of sections, 15 is the scale of the drawings (15 mm. = 1 m.), all the ordinates being taken from the drawings in millimetres, and only the final results being reduced to their natural values for the ship.

Calculation of A_0', B_0', A_1', B_1^1, V_0.

Formulæ—

$$A_0' = 2\int_{-L}^{+L}\int_{0}^{h} y \cos\frac{2\pi x}{\lambda_1}\,dx\,dz \qquad B_0' = 2\int_{-L}^{+L}\int_{0}^{h} y \sin\frac{2\pi x}{\lambda_1}\,dx\,dz$$

$$A_1' = 2\int_{-L}^{+L}\int_{0}^{h} y\,x \cos\frac{2\pi x}{\lambda_1}\,dx\,dz \qquad B_1' = 2\int_{-L}^{+L}\int_{0}^{h} y\,x \sin\frac{2\pi x}{\lambda_1}\,dx\,dz$$

$$V_0 = 2\int_{-L}^{+L}\int_{0}^{h} y\,dx\,dz.$$

Calculation of the Displacement V_0.

No. of the Sections. / No. of the W.L.	Bow Part. 1	2	3	4	Stern Part. 5	6	7	Sums.
I. ($z_1 = 0{\cdot}49^m$) ...	17·3	79·0	102·0	111·0	110·0	101·5	26·0	546·8
II. ($z_2 = 1{\cdot}85$)	13·0	73·0	99·0	108·5	106·0	95·5	7·0	502·0
III. ($z_3 = 2{\cdot}95$)	8·5	67·5	94·5	102·5	97·5	82·0	3·5	453·0
IV. ($z_4 = 4{\cdot}05$)	4·0	48·0	82·0	88·0	79·0	57·0	3·0	361·0
V. ($z_5 = 5{\cdot}41$)	1·0	12·0	41·0	41·0	28·5	18·0	3·0	144·5
Sums	43·8	276·5	418·5	451·0	425·0	354·0	42·5	2,007·3

$$V_0 = 2{,}007{\cdot}3 \times \frac{107 \times 5{\cdot}9}{7 \times 5 \times 15} = 2{,}007{\cdot}3 \times 2{\cdot}42 = 4{,}890^{cm.} = 5{,}000^{t}$$

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CALCULATION OF A_0', B_0', A_1', B_1 (ORDINATES NOT REDUCED).

I.	II.	III.	IV.	V.	VI.	VII.	VIII	IX.	X.	XI.	XII.	XIII.
No. of Section.	Abscisse x in Metres.	Sums s Bow Part.	Sums s Stern Part.	III. + IV.	III. − IV.	$\phi = \frac{2\pi x}{\lambda_1}$.	V. cos ϕ	V. sin ϕ	VI. cos ϕ	VI. sin. ϕ	X. x	XI. x
1 & 7	47·3	43·8	42·5	86·3	+ 1·3	96·3°	−9	86	0	1·3	0	4,070
2 & 6	28·4	276·5	354·0	630·5	−77·5	57·8°	336	532	−41	−65·1	−1,162	15,100
3 & 5	17·3	418·5	421·0	839·5	− 2·5	35·3°	686	486	− 2	− 1·5	− 35	8.410
4	0	451·0	—	451·0	—	0	451	0	451	0	0	0
							1,464			−65·3	−1,197	27,580

$A_0' = 1{,}464 \times 2{\cdot}42 = 3{,}520.$ $\quad A_1' = -1{,}197 \times 2{\cdot}42 = -2{,}890.$

$B_0' = -65{\cdot}3 \times 2{\cdot}42 = -156.$ $\quad B_1' = 27{,}580 \times 2{\cdot}42 = 66{,}500.$

CALCULATION OF E_1' AND F_1'.

Formulæ—

$$E_1' = 2\int_{-L}^{+L}\int_{0}^{h} z\, y \cos\frac{2\pi x}{\lambda_1}\, dx\, dz; \qquad F_1' = 2\int_{-L}^{+L}\int_{0}^{h} z\, y \sin\frac{2\pi x}{\lambda_1}\, dx\, dz.$$

To make the computing of these two expressions easier, it is convenient to replace z by $\frac{h}{2} + z - \frac{h}{2}$ and there will be obtained—

$$E_1' = 2\int_{-L}^{+L}\int_{0}^{h}\left(\frac{h}{2} + z - \frac{h}{2}\right) y \cos\frac{2\pi x}{\lambda_1}\, dx\, dz$$

$$= h\int_{-L}^{+L}\int_{0}^{h} y \cos\frac{2\pi x}{\lambda_1}\, dx\, dz + 2\int_{-L}^{+L}\int_{0}^{h}\left(z - \frac{h}{2}\right) y \cos\frac{2\pi x}{\lambda_1}\, dx\, dz;$$

remarking that—

$$2\int_{-L}^{+L}\int_{0}^{h} y \cos\frac{2\pi x}{\lambda_1}\, dx\, dz = A_0';$$

and putting—

$$Z_1 = z - \frac{h}{2} \quad \text{and} \quad E_1'' = 2\int_{-L}^{+L}\int_{-\frac{h}{2}}^{+\frac{h}{2}} z_1\, y \cos\frac{2\pi x}{\lambda_1}\, dx\, dz,$$

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we obtain—

$$E_1' = \frac{h}{2} A_0' + E_1'',$$

and in the same manner—

$$F_1' = \frac{h}{2} B_0' + F_1'',$$

where—

$$F_1'' = 2 \int_{-L}^{+L} \int_{-\frac{h}{2}}^{+\frac{h}{2}} z_1 y \sin \frac{2\pi x}{\lambda_1} \, dx \, dz.$$

No. of the Sections. / No. of the W. Lines.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
	$Z_1 = z - \frac{h}{2}$	1	2	3	4	5	6	7	VIII. + II.	VII. + III.	VI. + IV.	V.	II. − VIII.	III. − VII.	IV. − VI.	$Z_1 = z - \frac{h}{2}$
		Differences of Ordinates of W. Lines.														
I. − V.	−2·46	16	67	61	70	82	84	23	39	151	143	70	−7	−17	−21	−2·46
II. − IV.	−1·10	9	25	17	21	27	38	4	13	63	44	21	+5	−13	−10	−1·10
III.	0															
									Products by the Factor Z_1.							
									−96	−370	−351	−172	+17	+42	+51	
									−14	− 69	− 48	− 23	− 6	+14	+11	
		Sums						σ_1	−110	−439	−399	−195				
		Sums						σ_2					+11	+56	+62	
								$\sigma_1 \cos \frac{2\pi x}{\lambda_1}$	+12	−235	−326	−195				
								$\sigma_2 \sin \frac{2\pi x}{\lambda_1}$					11	48	35	

$$\Sigma \sigma_1 \cos \frac{2\pi x}{\lambda_1} = -744. \qquad \Sigma \sigma_2 \sin \frac{2\pi x}{\lambda_1} = 94.$$

$$E_1'' = 2{\cdot}42 \, . \, \Sigma \sigma_1 \cos \frac{2\pi x}{\lambda_1} = -744 \times 2{\cdot}42 = -1{,}790.$$

$$F_1'' = 2{\cdot}42 \, . \, \Sigma \sigma_2 \sin \frac{2\pi x}{\lambda_1} = 94 \times 2{\cdot}42 = 226.$$

$$E_1' = \frac{h}{2} A_0' + E'' = 2{\cdot}95 \times 3{,}520 - 1.790 = 8{,}600.$$

$$F_1' = \frac{h}{2} B_0' + F_1'' = 2{\cdot}95 \times (-156) + 226 = -234.$$

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CALCULATION OF G_1' AND H_1'

Formulæ—

$$G_1' = -\frac{4}{3}\frac{\pi}{\lambda_2}\int_{-L}^{+L}\int_{0}^{h} y^3 \cos\frac{2\pi x}{\lambda_1}\,dx\,dz.$$

$$H_1' = -\frac{4}{3}\frac{\pi}{\lambda_2}\int_{-L}^{+L}\int_{0}^{h} y^3 \sin\frac{2\pi x}{\lambda_1}\,dx\,dz.$$

No. of Sections. / No. of W. Lines.	1	2	3	4	5	6	7
	Cubes or Ordinates $\frac{y^3}{1,000}$						
I.	5	493	1,061	1,368	1,331	1,046	18
II.	2	389	970	1,277	1,191	871	0
III.	1	307	844	1,077	927	551	0
IV.	0	111	551	681	493	185	0
V.	0	17	69	69	23	6	0
Sums s	8	1,317	3,495	4,472	3,965	2,659	18
	18	2,659	3,965	—			
Sum σ_1... ...	26	3,976	7,460	4,472			
Differences σ_2 ...	−10	−1,342	−470	—			
$\sigma_1 \cos\frac{2\pi x}{\lambda_1}$ ...	− 3	2,024	6,086	4,472	$\Sigma\,\sigma_1 \cos\frac{2\pi x}{\lambda_1} = 12{,}587.$		
$\sigma_2 \sin\frac{2\pi x}{\lambda_2}$ ...	−10	−1,136	−272	0	$\Sigma\,\sigma_2 \sin\frac{2\pi x}{\lambda_1} = -1{,}418.$		

$$-\frac{\lambda_2}{2\pi}G_1' = 2\int_{-L}^{+L}\int_{0}^{h} y^3 \cos\frac{2\pi x}{\lambda_1}\,dx\,dz = \frac{2\times 107\times 5{\cdot}9\times 1000}{7\times 5\times 15\times 15\times 15}\,\Sigma\,\sigma_1 \cos\frac{2\pi x}{\lambda_1} = 135{,}000 = G_1''.$$

$$-\frac{\lambda_2}{2\pi}H_1' = 2\int_{-L}^{+L}\int_{0}^{h} y^3 \sin\frac{2\pi x}{\lambda_1}\,dx\,dz = 10{\cdot}69\,\Sigma\,\sigma_2 \sin\frac{2\pi x}{\lambda_1} = -12{,}700 = H_1''.$$

The numbers 107 and 5·9 are the length and the draught of the ship; 7 and 5, the number of the sections and of the water lines, and the factor $\frac{1{,}000}{15^3}$ is introduced because the ordinates were taken in millimetres from the drawings, and 15 millimetres of the scale are 1 metre, and the cubes were divided by 1,000 in order not to introduce useless figures in the numerical computation. Calculating in the same manner for all the other values of the head angle α from point to point between 0° and 180°, we obtain the following results given by the following table :—

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TABLE OF THE VALUES OF THE PARAMETERS (40′).

a	a_0'	b_0'	a_1'	b_1'	g_1''	h_1''	A_0'	B_0'	A_1'	B_1'	E_1'	F_1'	G_1''	H_1''
Deg.														
0	475	−75	771	19,950	28,200	−6,700	2,470	−171	− 942	72,600	6,210	−239	100,100	−18,010
11¼	514	−77	620	20,200	29,000	−6,620	2,560	−185	−1,140	76,500	6,430	−283	108,000	−17,910
22½	556	−77	361	20,050	31,000	−6,520	2,770	−285	−1,570	75,000	6,910	−288	113,500	−17,560
33¾	647	−77	− 45	19,850	34,000	−6,130	3,100	−173	−2,010	72,600	7,690	−264	123,500	−16,600
45	766	−75	− 687	18,700	37,800	−5,670	3,520	−156	−2,890	66,500	8,600	−234	135,000	−15,150
56¼	903	−68	−1,446	16,280	42,100	−4,790	4,010	−132	−3,880	56,700	9,670	−197	148,000	−12,700
67½	1,040	−49	−2,310	12,240	46,200	−3,140	4,500	− 86	−4,610	38,600	10,800	−124	161,500	− 8,450
78¾	1,095	−35	−2,650	8,250	47,700	−2,240	4,690	− 63	−4,960	27,500	11,170	− 92	166,500	− 6,040
90	1,150	0	−2,980	0	49,200	0	4,830	0	−5,360	0	11,550	0	170,000	0
101¼	1,095	+35	−2,650	− 8,250	47,700	+2,240	4,690	+ 63	−4,960	−27,500	11,170	+ 92	166,500	+ 6,970
112½	1,040	+49	−2,310	−12,240	46,200	+3,140	4,500	+ 86	−4,610	−38,600	10,800	+124	161,500	+ 8,450
123¾	903	+68	−1,446	−16,280	42,100	+4,790	4,010	+132	−3,880	−56,700	9,670	+197	148,000	+12,700
135	766	+75	− 687	−18,700	37,800	+5,670	3,520	+156	−2,890	−66,500	8,600	+234	135,000	+15,150
146¼	647	+77	− 45	−19,850	34,000	+6,130	3,100	+173	−2,010	−72,600	7,690	+264	123,500	+16,600
157½	556	+77	+ 361	−20,050	31,000	+6,520	2,770	+185	−1,570	−75,000	6,910	+288	113,500	+17,560
168¾	517	+77	+ 620	−20,200	29,000	+6,620	2,560	+185	−1,140	−76,500	6,430	+283	108,000	+17,910
180	475	+75	+ 771	−19,950	28,200	+6,700	2,470	+171	− 942	−72,600	6,210	+239	100,100	+18,010

These values being calculated, we make of them the following combinations by which they enter into the equations of the rotational motion of the ship:—

$$N_1' = \frac{F_1' - \frac{\lambda_2}{\lambda} H_1' + \frac{\lambda_2}{2\pi} h_1'}{V_0 (r_0 - a)} = \frac{F_1' + \frac{2\pi}{3\lambda} H_1'' - \frac{1}{3} h_1''}{V_0 (r_0 - a)};$$

$$M_1' = \frac{E_1' - \frac{\lambda_2}{\lambda} G_1' + \frac{\lambda_2}{2\pi} g_1}{V_0 (r_0 - a)} = \frac{E_1' + \frac{2\pi}{3\lambda} G_1'' - \frac{1}{3} g_1''}{V_0 (r_0 - a)}$$

$$K_1' \cos a = \frac{\left(\frac{\lambda_1}{\lambda} A_1' - F_1' - \frac{\lambda_1}{2\pi} a_1'\right) \cos a}{V_0 (R_0 - a)} = \frac{A_1' - F_1' \cos a - \frac{\lambda}{2\pi} a_1'}{V_0 (R_0 - a)};$$

$$L_1' \sin a = \frac{\left(\frac{\lambda_1}{\lambda} B_1' - E_1' - \frac{\lambda_1}{2\pi} b_1'\right) \cos a}{V_0 (R_0 - a)} = \frac{B_1 - E_1' \cos a - \frac{\lambda}{2\pi} a_1'}{V_0 (R_0 - a)}$$

$$P_1' = (G_1' \cos a + B_1' \sin a) \frac{1}{V_0} = \left[- \frac{2\pi}{3\lambda} G_1'' \cos a + B_1' \right] \frac{\sin a}{V_0}$$

$$Q_1 = [H_1' \cos a + A_1' \sin a] \frac{1}{V_0} = \left[- \frac{2\pi}{3\lambda} H_1'' \cos a + A_1' \right] \frac{\sin a}{V}$$

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TABLE OF THE VALUES OF THE CO-EFFICIENTS N_1', M_1', $K_1' \cos \alpha$, $L_1' \sin \alpha$, P_1', Q_1'.

α	N_1'	M_1'	$K_1' \cos \alpha$	$L_1' \sin \alpha$	P_1'	Q_1'
Deg. 0	−0·585	−0·320	−0·024	−0·500	0	0
11¼	−0·587	−0·301	−0·020	−0·502	2·84	−0·010
22½	−0·582	−0·311	−0·017	−0·500	5·47	−0·059
33¾	−0·545	−0·330	−0·001	−0·497	7·80	−0·151
45	−0·502	−0·376	+0·016	−0·488	8·91	−0·342
56¼	−0·420	−0·390	+0·038	−0·412	8·91	−0·600
67½	−0·274	−0·409	+0·063	−0·316	6·67	−0·840
78¾	−0·198	−0·436	+0·072	−0·211	5·17	−0·985
90	0·000	−0·438	+0·082	0·000	0	−1·073
101¼	+0·198	−0·436	+0·072	+0·211	−5·17	−0·985
112½	+0·274	−0·409	+0·063	+0·316	−6·67	−0·840
123¾	+0·420	−0 390	+0·038	+0·412	−8·91	−0·600
135	+0·502	−0·376	+0·016	+0·488	−8·91	−0·342
146¼	+0·545	−0·330	−0·001	+0·497	−7·80	−0·151
157½	+0·582	−0·311	−0·017	+0·500	−5·47	−0·059
168¾	+0·587	−0·301	−0·020	+0·502	−2·84	−0·010
180	+0·585	−0·320	−0·024	+0·500	0	0

Remark.—In computing this table it was taken that $V_0 (r_0 - a) = 4{,}740$, and $V_0 (R_0 - a) = 664{,}000$.

§ 9. The values of all the co-efficients were calculated on taking no account of the progressive diminution of the radii of the generating circles. It was pointed out that, to obtain a closer first approximation for the rolling, it is necessary to take this diminution into account, introducing the reduction factor $e^{-\frac{2\pi z}{\lambda}}$, so that—

$$\left.\begin{aligned} A_0' &= 2\int_{-L}^{+L}\int_{0}^{h} y\, e^{-\frac{2\pi z}{\lambda}} \cos\frac{2\pi x}{\lambda_1}\, dx\, dz; & B_0' &= 2\int_{-L}^{+L}\int_{0}^{h} y\, e^{-\frac{2\pi z}{\lambda}} \sin\frac{2\pi x}{\lambda_1}\, dx\, dz \\ E_0' &= 2\int_{-L}^{+L}\int_{0}^{h} y\, z\, e^{-\frac{2\pi z}{\lambda}} \cos\frac{2\pi x}{\lambda_1}\, dx\, dz; & F_1' &= 2\int_{-L}^{+L}\int_{0}^{h} y\, z\, e^{-\frac{2\pi z}{\lambda}} \sin\frac{2\pi x}{\lambda_1}\, dx\, dz \\ G_1' &= -\frac{4\pi}{3\lambda_2}\int_{-L}^{+L}\int_{0}^{h} y^3 e^{-\frac{2\pi z}{\lambda}} \cos\frac{2\pi x}{\lambda_1}\, dx\, dz; & H_1 &= -\frac{4\pi}{3\lambda_2}\int_{-L}^{+L}\int_{0}^{h} y^3 e^{-\frac{2\pi z}{\lambda}} \sin\frac{2\pi x}{\lambda_1}\, dx\, dz \end{aligned}\right\} \quad (40'')$$

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and we shall obtain the following table:—

TABLE OF THE VALUES OF A_0', B_0', E_1', F_1', G_1', H_1', M_1', AND N_1' FOR REDUCED ORDINATES.

α	A_0'	B_0'	E_1'	F_1'	G_1'	H_1'	M_1'	N_1'
Deg. 0	2,160	−171	5,230	−241	91,200	−16,800	−0·590	−0·558
11¼	2,240	−169	5,420	−237	96,700	−16,700	−0·555	−0·550
22½	2,420	−168	5,840	−234	103,000	−16,300	−0·579	−0·542
33¾	2,690	−160	6,400	−224	111,000	−15,600	−0·641	−0·512
45	3,100	−112	7,310	−193	122,000	−14,100	−0·647	−0·470
56¼	3,540	−120	8,030	−164	133,500	−11,800	−0·790	−0·396
67½	3,940	− 77	9,080	− 96	146,000	− 7,850	−0·825	−0·257
78¾	4,120	− 58	9,480	− 80	150,000	− 5,620	−0·830	−0·171
90	4,260	0	9,800	0	154,000	0	−0·850	0
101¼	4,120	+ 58	9,480	+ 80	150,000	+ 5,620	−0·830	+0·171
112½	3,940	+ 77	9,080	+ 96	146,000	+ 7,850	−0·825	+0·257
123¾	3,540	+120	8,030	+164	133,500	+11,800	−0·790	+0·396
135	3,100	+142	7,310	+193	122,000	+14,100	−0·647	+0·470
146¼	2,690	+160	6,400	+224	111,000	+15,600	−0·641	+0·512
157½	2,420	+168	5,840	+234	103,000	+16,300	−0·579	+0·542
168¾	2,240	+169	5,420	+237	96,700	+16,700	−0·555	+0·550
180	2,160	+171	5,230	+241	91,200	+16,800	−0·590	+0 558

This table, being compared with the preceding one, shows that, although the variation in the values of A_0', B_0', &c., does not surpass 15 per cent. of their respective values, the variation in the co-efficients M_1' and N_1' is from one to two. The amplitude of the "forced" rolling oscillations being directly proportional to M_1' and N_1', this shows that, in order to obtain with any degree of accuracy the rolling produced by given regular waves, we must know exactly their dynamical structure, because it has a great influence on the amplitude of the rolling produced by these waves. It is quite the inverse for the pitching, which will be obtained with a good approximation, even if the dynamical structure of the wave be but roughly known.

§ 10. In order to form the numerical equations of the motion of the ship, after having computed the values of the parameters which characterise the action of the wave on her, it remains to obtain (1) the principal moments of inertia of the ship A, B, C; and (2) the resistance of water to her oscillatory motion.

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It is a very tedious operation to compute exactly the moment of inertia of a ship.

To obtain A, the moment about the longitudinal axis for a ship afloat, we can content ourselves with the very well-known experience to determine the period of her "free" oscillations on still water, and to use the relation—

$$T = 2\pi \sqrt{\frac{A}{P(r_0 - a)}}$$

The moment A, thus obtained, is the moment of inertia of the ship, together with that mass of water which takes part in her motion, making, so to say, a single body with her.

The same method would also give the value of the moment of inertia B about the transverse axis, if the period of the free pitching be observed; but such a method is only applicable to small ships; because it is almost impossible to set a big ship pitching in still water. Fortunately a sufficiently approximate value of B can be easily calculated, as shown in my paper on pitching, by taking the moment of inertia of the displacement of the ship in respect to her middle plane. This approximation becomes very much improved if the distribution of the principal weights be taken into account. Indeed—

$$B = \Sigma m (x^2 + z^2) = \Sigma m x^2 + \Sigma m z^2,$$

and—

$$A = \Sigma m (z^2 + y^2) = \Sigma m z^2 + \Sigma m y^2,$$

thus—

$$\Sigma m x^2 < B < \Sigma m x^2 + A, \qquad (45)$$

all the sums relating to all the masses constituting the structure and loads of the ship.

If the distribution of loads is calculated, and represented by a curve, as in Sir E. Reed's paper on stresses, the sum $\Sigma m x^2$ represents the moment of inertia of the area of this curve about the axis passing through her centre of gravity. Having calculated this moment $\Sigma m x^2$, and putting—

$$B = \Sigma m x^2 + \frac{1}{2} A,$$

we are sure that the error in the value of B is less than $\frac{1}{2}$ A.

Generally A is very small if compared with B; for instance, for the *Korniloff* B is 318,000 (ton metres) and A only 20,000, so that $\frac{A}{B} < \frac{1}{15}$, and thus the degree of approximation of the formula—

$$B = \Sigma m x^2 + \frac{1}{2} A$$

is at least 3 per cent., and we can be sure that it is even much better, because the sums $\Sigma m z^2$ and $\Sigma m y^2$ cannot be very different from one another for the usual forms of ships. This approximation is far superior to what is necessary.

To obtain the value of C it may be remarked that—

$$C = \Sigma m (x^2 + y^2) = \Sigma m x^2 + \Sigma m y^2,$$

thus, approximately—

$$C = \Sigma m x^2 + \frac{1}{2} A = B. \qquad (46)$$

§ 11. The exact law of resistance of water is as yet unknown; we aid our ignorance about this matter by more or less plausible suppositions, which are more or less confirmed by experience and the few exact observations which have been made. I need not relate the investigations of

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M. Bertin and Messrs. Froude, father and son. These authorities represent the effect of resistance on the rolling by one of the "extinction laws"—

$$\left.\begin{aligned} \Delta\,\Theta_m &= -\,a_1\,\Theta_m \quad \ldots\ldots\ldots\ (1)\\ \Delta\,\Theta_m &= -\,b_2\,\Theta_m{}^2 \quad \ldots\ldots\ldots\ (2)\\ \Delta\,\Theta_m &= -\,[a_3\,\Theta_m + b_3\,\Theta_m{}^2] \quad \ldots\ (3) \end{aligned}\right\} \qquad (17)$$

where Θ_m is the amplitude of the m^{th} roll, and $\Delta\,\Theta_m = \Theta_{m+1} - \Theta_m$ is the difference of this amplitude and the following one. The co-efficients are generally determined experimentally by rolling a ship on still water, and then the same law of extinction is applied to calculate the greatest amplitude of rolling on given uniform waves, whether synchronous with the ship or not.

It can be easily shown, by the method which Poisson explains in his "Mécanique" (§§ 188 and 189), that, for small amplitudes these three laws of extinction are obtained when resistance is supposed proportional either to the first power of the velocity, or to its square, or is expressed by a binomial formula $a\,v + b\,v^2$.

In order that the reader may, at a single glance, decide on the approximation of such relations, and of the suppositions used to obtain them, I will deduce the formulæ which express the relation between the co-efficients of extinction and the co-efficients of resistance.

The equations of the small free oscillations of the body would in these three cases be :—

$$\left.\begin{aligned} \frac{d^2\theta}{dt^2} + 2\,h\frac{d\theta}{dt} + n^2\theta &= 0 \quad \ldots\ (1')\\ \frac{d^2\theta}{dt^2} \pm k\left(\frac{d\theta}{dt}\right)^2 + n^2\theta &= 0 \quad \ldots\ (2') \text{ and}\\ \frac{d^2\theta}{dt^2} + 2\,h\frac{d\theta}{dt} \pm k\left(\frac{d\theta}{dt}\right) + n^2\theta &= 0 \quad \ldots\ (3') \end{aligned}\right\} \qquad (48)$$

the sign (+) is to be taken when the oscillation is performed in the sense of increasing values of θ, and (−) if it is in the sense of decreasing values of θ.

We will integrate all these equations, adopting the same initial conditions, *i.e.*, that, for $t = 0$,

$$\theta = \theta_0, \text{ and } \left(\frac{d\theta}{dt}\right) = 0.$$

Then equation (1') gives—

$$\theta = e^{-ht}\{C_1\cos n_1 t + C_2 \sin n_1 t\}$$

where—

$$n_1 = \sqrt{n^2 - h^2}$$

C_1 and C_2 are determined by the conditions—

$$\theta_0 = C_1, \text{ and } 0 = -\,h\,C_1 + n_1 C_2;$$

hence—

$$C_2 = \frac{k\,\theta_0}{n_1}$$

and—

$$\theta = \Theta_0\,e^{-ht}\left(\cos n_1 t + \frac{h}{n_1}\sin n_1 t\right) \qquad (1'')$$

The inclination Θ reaches its extreme values—

$$\theta_0, -\theta_1, \theta_2, -\theta_3, \text{ \&c.},$$

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at the instants—

$$0, \quad \frac{\pi}{n_1}, \quad \frac{2\pi}{n_1}, \quad \frac{3\pi}{n_1}, \quad \&c.,$$

denoting by $T = \frac{2\pi}{n_1}$ the period of a complete oscillation, we obtain, in absolute values—

$$\theta_1 = \theta_0 e^{-\frac{hT}{2}}; \quad \theta_2 = \theta_0 . e^{-2\frac{hT}{2}}; \quad \theta_3 = \Theta_0 e^{-3\frac{hT}{2}} \ldots . \ \Theta_m = \Theta_0 e^{-m\frac{hT}{2}}; \quad \Theta_{m+1} = \Theta_0 e^{-(m+1)\frac{hT}{2}} \ldots$$

hence—

$$\Delta \Theta_m = \Theta_{m+1} - \Theta_m = -\Theta_0 e^{-m\frac{hT}{2}}\left(1 - e^{-\frac{hT}{2}}\right) = -\Theta_m\left(1 - e^{-\frac{hT}{2}}\right)$$

which, being compared with the formula—

$$-\Delta\theta_m = a_1 \Theta_m$$

gives—

$$a_1 = 1 - e^{-\frac{hT}{2}}$$

and inversely—

$$h = -\frac{2}{T}\log_e(1 - a_1) = -\frac{0{\cdot}8686}{T}\log(1 - a_1) \qquad \text{I.}$$

In accordance with the initial conditions the equation (2′) will be, for the first half oscillation—

$$\frac{d^2\theta}{dt^2} - \kappa\left(\frac{d\theta}{dt}\right)^2 + n^2\theta = 0 \qquad (2')$$

This equation can be integrated by quadratures; but, as the equation itself, for the case of a ship, is only an approximate one, we need only obtain a solution of the same degree of approximation as the equation itself. This can be done either by successive approximations or by expansion in series, proceeding in powers of θ_0; this last method is a shorter and a more symmetrical one, and thus we shall put with Poisson—

$$\theta = \theta_0 . \varphi_1(t) + \theta_0^2 \varphi_2(t) + \theta_0^3 \varphi_3(t) + \ldots \qquad (49)$$

where $\phi_1(t)$; $\phi_2(t)$, &c., are unknown functions of t to be determined in such a manner that θ satisfies the equation and the initial conditions.

Substituting the above value of θ in the equation, we obtain, after having collected the terms containing the same power of θ_0—

$$\theta_0[\varphi_1''(t) + n^2\varphi_1(t)] + \theta_0^2[\varphi_2''(t) - \kappa[\varphi_1'(t)]^2 + n^2\varphi_2(t)] + \ldots = 0 \qquad (50)$$

We have not inserted the terms with θ_0^3, &c., because, in equation (2′) they have already been neglected.

The equation (50) must be satisfied, whatever be the value of θ_0; thus the quantities which multiply every power of θ_0 must separately be zero; hence to determine ϕ_1 and ϕ_2 we have the following equations and initial conditions—

$$\varphi_1'' + n^2\varphi_1 = 0; \quad \text{when } t = 0, (\varphi_1)_0 = 1; \ (\varphi_1')_0 = 0.$$
$$\varphi_2'' + n^2\varphi_2 = \kappa\varphi_1'^2; \text{ when } t = 0, (\varphi_2)_0 = 0; \ (\varphi_2')_0 = 0.$$

From the first of these equations we obtain—

$$\varphi_1 = \cos nt,$$

which, being substituted in the second, gives—

$$\varphi_2'' + n^2\varphi_2 = \kappa n^2 \sin^2 nt = \frac{1}{2}\kappa n^2(1 - \cos 2nt),$$

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the general integral of which is—

$$\phi_2 = C_1 \cos n t + C_2 \sin n t + \frac{1}{2}\kappa + \frac{\kappa}{6} \cdot \cos 2 n t.$$

The initial conditions give for the arbitrary constants the values satisfying the equations—

$$0 = C_1 + \frac{\kappa}{6} + \frac{\kappa}{2}; \qquad \therefore C_1 = -\frac{2}{3}\kappa.$$

$$0 = n C_2; \qquad C_2 = 0,$$

and $\therefore$

$$\phi_2 = \frac{1}{2}\kappa - \frac{2}{3}\kappa \cos n t + \frac{1}{6}\kappa \cos 2 n t,$$

and—

$$\theta = \left(\theta_0 - \frac{2}{3}\kappa\theta_0\right) \cos n t + \frac{\kappa\theta_0^2}{2}\left(1 + \frac{1}{3}\cos 2 n t\right) \qquad (51)$$

This equation can only be used so long as θ' remains negative; while t reaches the least value satisfying the equation—

$$\theta' = 0 = -n\left(\theta_0 - \frac{2}{3}\kappa\theta_0^2\right) \sin n t - \frac{n\kappa\theta_0^2}{3} \sin 2 n t,$$

which gives—

$$n t = \pi, \text{ or } t = \frac{T}{2} = \frac{\pi}{n}.$$

The corresponding value of θ is—

$$\theta_1 = -\left(\theta_0 - \frac{4}{3}\kappa\theta_0^2\right)$$

hence—

$$-\Delta\theta_0 = \frac{4}{3}\kappa\theta_0^2$$

Quite in the same manner for the m^{th} oscillation it would be obtained—

$$-\Delta\theta_m = \frac{4}{3}\kappa\theta_m,$$

which, being compared with the formula (2), gives—

$$\kappa = \frac{3}{4}h_2. \qquad \text{II.}$$

Finally, in the third case, when the equation for the first half oscillation is—

$$\frac{d^2\theta}{dt^2} + 2h\frac{d\theta}{dt} + n^2\theta - \kappa\left(\frac{d\theta}{dt}\right)^2 = 0 \qquad (3')$$

the same method being applied, the functions ϕ_1 and ϕ_2 are determined by the following equations and initial conditions—

$$\phi_1'' + 2h\phi_1' + n^2\phi_1 = 0; \quad \text{and for } t = 0 \quad (\phi_1)_0 = 1; \ (\phi_1')_0 = 0;$$

$$\phi_2'' + 2h\phi_2' + n^2\phi_2 = \kappa\phi_1^2; \qquad (\phi_2)_0 = 0; \ (\phi_2')_0 = 0;$$

hence—

$$\phi_1 = e^{-ht}\left[\cos n_1 t + \frac{h}{n_1}\sin n_1 t\right]$$

where—

$$n_1 = n^2 - h^2, \quad \text{and } n_1 = +\sqrt{n^2 - h^2}$$

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Then the equation for ϕ_2 will be—

$$\phi_2'' + 2h\phi_2' + n^2\phi_2 = \frac{\kappa n^4}{2n_1^2} e^{-2ht}(1 - \cos 2n_1 t);$$

the general integral of which is—

$$\phi_2 = e^{-ht}\{C_1 \cos n_1 t + C_2 \sin n_1 t\} + A e^{-2ht} + e^{-2ht}\{B \cos 2n_1 t + D \sin 2n_1 t\},$$

where—

$$A = \frac{\kappa n^2}{2n_1^2}$$

and B and D are determined by the equations—

$$(4h^2 - 3n^2)B - 4n_1 h D = -\frac{\kappa n^4}{2n_1^2};$$

$$4n_1 h D + (4h^2 - 3n^2)D = 0;$$

hence—

$$B = -\frac{\kappa n^4}{2n_1^2} \cdot \frac{4h^2 - 3n^2}{(4h^2 - 3n^2)^2 + 16 n_1^2 h^2} = -\frac{\kappa n^2}{2n_1^2} \cdot \frac{4h^2 - 3n^2}{9n^2 + 8h}$$

$$D = \frac{\kappa n^4}{2n_1^2} \cdot \frac{4hn_1}{(4h^2 - 3n^2)^2 + 16 n_1^2 h} = \frac{2\kappa n^2}{n_1} \cdot \frac{h}{9n^2 + 8h}$$

and the arbitrary constants, if determined according to the initial conditions, are—

$$C_1 = -(A + B), \quad \text{and} \quad C_2 = \frac{h}{n_1}(A + B) - 2D,$$

A, B, and D having the above values.

It may be remarked that, generally, the ratio $\frac{h^2}{n^2}$ is a very small one, so that practically $n_1 = n$, then all the above formulæ are greatly simplified, and we will have simply—

$$A = \frac{1}{2}\kappa; \quad B = \frac{1}{6}\kappa; \quad D = \frac{2}{9}\frac{h\kappa}{n}; \quad C_1 = -\frac{2}{3}\kappa; \quad C_2 = \frac{2}{9}\frac{h\kappa}{n};$$

and—

$$\phi_2 = e^{-ht}\left\{-\frac{2}{3}\kappa \cos n_1 t + \frac{2}{9}\frac{h\kappa}{n}\sin n_1 t\right\} + \frac{1}{2}\kappa e^{-2ht} + e^{-2ht}\left\{\frac{1}{6}\kappa \cos 2n_1 t + \frac{2}{9}\frac{h\kappa}{n}\sin 2n_1 t\right\}$$

and—

$$\left.\begin{aligned}\theta = \theta_0\phi_1 + \theta_0^2\phi_2 = e^{-ht}\left[\left(\theta_0 - \frac{2}{3}\kappa\theta_0^2\right)\cos nt + \left(\frac{h\theta_0}{n} + \frac{2}{9}\frac{\kappa h}{n}\theta_0^2\right)\sin nt\right] \\ + e^{-2ht}\left[\frac{\kappa\theta_0^2}{2} + \frac{\kappa\theta_0^2}{6}\cos 2nt + \frac{2}{9}\frac{\kappa h}{n}\theta_0^2 \sin 2nt\right]\end{aligned}\right\} \quad (52)$$

The maximum inclination θ_1, on the other side of upright position, is reached at the moment determined by the equation :—

$$\theta' = 0 = e^{-ht}\left[\frac{8}{9}\kappa h\theta_0^2 \cos nt - \left(n\theta_0 - \frac{2}{3}n\kappa\theta_0^2\right)\sin nt\right]$$

$$+ e^{-2ht}\left(-h\kappa\theta_0^2 + \frac{1}{9}h\kappa\theta_0^2 \cos 2nt - \frac{1}{3}n\kappa\theta_0^2 \sin 2nt\right)$$

in which the quantity $n^2 + h^2$ was simply replaced by n^2.

An approximate value of the least root of this equation is near to $t = \frac{\pi}{n}$, and the corresponding value of θ, retaining only its most important terms, is—

$$\theta_1 = -\left(\theta_0 - \frac{2}{3}h\theta_0^2\right)e^{-\frac{h\pi}{n}} + \frac{2}{3}e^{-\frac{2h\pi}{n}} \cdot \kappa\theta_0^2 = -\theta_0 e^{-\frac{h\pi}{n}}\left[1 - \frac{2}{3}\kappa\theta_0\left(1 + e^{-\frac{h\pi}{n}}\right)\right]$$

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Quite in the same manner for the $(m+1)$ amplitude, we should have the formula—

$$\theta_{m+1} = -\theta_m \cdot e^{-\frac{h\pi}{n}}\left[1 - \frac{2}{3}\kappa\theta_m\left(1 + e^{-\frac{h\pi}{n}}\right)\right]$$

hence in absolute value—

$$\Delta\theta_m = \theta_m - \theta_{m+1} = -\left[\left(1 - e^{-\frac{h\pi}{n}}\right)\theta_m + \frac{2}{3}\kappa e^{-\frac{h\pi}{n}}\left(1 + e^{-\frac{h\pi}{n}}\right)\theta_m^2\right]$$

which, being compared with the formula—

$$\Delta\theta_m = -(a_3\theta_m + b_3\theta_m^2),$$

gives the relations—

$$\left.\begin{aligned} a_3 &= 1 - e^{-\frac{hT}{2}} \\ b_3 &= \frac{2}{3}\kappa e^{-\frac{hT}{2}}\left(1 + e^{-\frac{hT}{2}}\right) \end{aligned}\right\} \qquad \text{III.}$$

where $\frac{T}{2} = \frac{\pi}{n}$ is half the period of oscillations.

By this relation, when a_3 and b_3 are known, h and k can be immediately determined.

It may be remarked that the relation III. contains the former two as particular cases. If we put $k = 0$, we obtain form I., and putting $h = 0$ we obtain II. I entered into these details, not only to obtain these known results, but to show the use of Poisson's method for the expansion in series of the solution of the above differential equations. This method being of great importance in many questions connected with the dynamics of a ship, it suffices to mention the investigation of rolling for greater amplitudes, and to take account of the real form of the diagram of stability.

§ 12. There is a very remarkable case when extinction is independent of the amplitude; it arises in ships or models fitted with water chambers. A systematical investigation of this subject was made, and is not yet finished, by a colleague of mine, Professor Boubnoff, who has allowed me to state the results which he has already arrived at.

(1) To obtain the best extinction by a water chamber, the depth of water in it must be such that the time required for a translational (Scott Russell's) wave to travel over the whole extent of the chamber across the ship be equal to the half period of her complete oscillation; or, what is the same thing, to the period of her single roll; so that, denoting by b the extent of the chamber, by v the velocity of the above-said wave, and by T the complete period, these quantities must hold the relation—

$$\frac{T}{2} = \frac{b}{v} \qquad (53)$$

(2) The velocity of the translational wave can be calculated by the well-known formula—

$$v = \sqrt{g(h+f)} \qquad (54)$$

where f is the height of the wave, and h the depth of water in the chamber.

(3) If the depth of water in the chamber is regulated according to the above rule, the extinction produced by the chamber is independent of the amplitude of roll, and therefore constant.

(4) The value of this constant seems to be in a direct ratio to the quantity of water in the chamber, to its extent b, and in an inverse ratio to the displacement and metacentric height of the ship; it seems also to increase with the elevation of the chamber above the C.G. of the ship.

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The study not being completed, these results were obtained on experiments made on a pendulum arrangement; now the experiments are being repeated on a model in the experimental tank, and will be continued on barges, and finally on a transport steamer; and, as they are of general interest, they will be fully communicated to this Institution by Professor Boubnoff himself.

The theoretical reason of the constancy of extinction, which on the pendulum arrangement appears in its purest form, is as follows:—The translational wave, after having travelled over the whole extent of the chamber, meets the side, and, after a blow on it, is partly annihilated, partly reflected. The effects of such blows, and of the change of position of the C.G., occurring periodically at equidistant instants, such as the half period of oscillation of the pendulum, is equivalent to a periodical force of the same period. Then the equation of the motion of the pendulum will be of the form—

$$\frac{d^2\theta}{dt^2} + n^2\theta = \kappa \sin nt \qquad (55)$$

The integral of which, the initial conditions being, say, $\theta = \theta_0$ and $\theta' = 0$ at the instant $t = 0$, is—

$$\theta = \theta_0 \cos nt + \frac{\kappa}{n^2} \sin nt - \frac{\kappa}{2n} t \cos nt \qquad (56)$$

and we see that, at the successive instants—

$$0, \quad \frac{\pi}{n}, \quad \frac{2\pi}{n}, \quad \frac{3\pi}{n}, \quad \&c.,$$

the respective values of θ, are—

$$\theta_0; \quad -\left(\theta_0 - \frac{\kappa\pi}{2n}\right); \quad +\left(\theta_0 - 2\frac{\kappa\pi}{2n}\right); \quad -\left(\theta_0 - 3\frac{\kappa\pi}{2n}\right), \ \&c.$$

which show that the extinction is constant, and equal to $\frac{\kappa\pi}{2n} = \kappa \cdot \frac{T}{4}$, where $T = \frac{2\pi}{n}$ is the period of a complete oscillation of the ship.

Experiment shows that, when the maximum angle of inclination is less than $\frac{\kappa\pi}{2n}$, the pendulum comes to rest, and makes no excursion on the other side of the upright position. The behaviour of a model is analogous to that of a pendulum, though the phenomenon has not such a pure form.

§ 13. Thus it is shown that, whatever the law of extinction in still water be, it can be represented by terms introduced into the differential equation of the motion of the ship, and will then be represented by an analytical expression, having the advantage that the influence of the variation of every one of the constituent terms may be readily ascertained in a quantitative form, and not only as a qualificative one.

If it could be admitted that the resistance to the oscillations of the ship on waves is the same as in still water, we could immediately form the equations of her motion. We can be sure that such a supposition is far from being a rigorous one; but, as there does not exist anything better, we may be content with this supposition being practically admitted.

Poisson's method, or that of successive approximations, will give easily the required solution of the equation thus formed; and, as they take their simplest form in the case of resistance proportional to the simple velocity, we shall consider only this case in order to illustrate by a numerical example our general results.

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In this case the equations of the motion of the ship are linear, with constant co-efficients, and will have the form—

$$u'' + 2\,h\,u' + n^2\,u = \kappa \sin p\,t + m \cos p\,t \qquad (57)$$

and their general integral is of the form—

$$n = e^{-h\,t}(C_1 \cos n_1\,t + C_2 \sin n_1\,t) + M \sin p\,t + N \cos p\,t \qquad (58)$$

where M and N are determined by the equations—

$$(n^2 - p^2)\,M - 2\,h\,p\,N = \kappa$$
$$2\,h\,p\,M + (n^2 - p^2)\,N = m$$

and—

$$n_1 = \sqrt{n^2 - h^2}$$

thus—

$$M = \frac{(n^2 - p^2)\,\kappa + 2\,h\,p\,m}{(n^2 - p^2)^2 + 4\,h^2\,p^2}\,; \qquad N = \frac{(n^2 - p^2)\,m - 2\,h\,p\,\kappa}{(n^2 - p^2)^2 + 4\,h^2\,p^2} \qquad (59)$$

The terms—

$$e^{-h\,t}(C_1 \cos n_1\,t + C_2 \sin n_1\,t)$$

represent the so-called "free" oscillations, and the terms—

$$M \sin p\,t + N \cos p\,t$$

the "forced" oscillations; and the expression of the former shows that, by the presence of the exponential $e^{-h\,t}$, the free oscillations are gradually evanescent, and the motion becomes ultimately independent of the initial conditions, and will only consist of forced oscillations.

But such an independency will only exist if the waves are ideally regular, so that their action may be expressed by the two right-hand terms of the above equation. But such a regularity is seldom to be expected at sea. Every individual wave can be represented by the trochoid or sinusoid of the corresponding period, but the whole system will consist of a succession of waves of different periods.

Let us, for instance, suppose that the heaving of the sea consists of a succession of waves, say, of the following periods :—

8·2; 7·7; 7·5; 8·5; 7·7; 8·5; 7·5; 7·7; 8·5; 7·5; 8·5; 8·5; 7·7 seconds . . . &c. (60)

Such a heaving would appear to an observer on board as an extremely regular one, because it is impossible to distinguish the fractions of a second in observing the period of every individual wave; such a precision is only attained after a systematic and patient exercise in the observations with a transit instrument used by the astronomers; but the passage of the crest of a wave through a marked point of the ship is far from being so neatly defined as the transit of the brilliant image of a star through the spider threads of the reticule of the instrument. Every observer at sea would say that the above system of waves was a very regular one with a period of 8″, which is the mean of the real ones.

But the effect of such a system of waves on the *rolling* which they would produce on a ship is quite different from that produced by the regular waves.

To make this difference clearer, let us denote by $\tau_1, \tau_2, \tau_3 \ldots$ the periods of the successive waves, then equation (57) holds good for every single wave; thus, for the first one we should have—

$$u'' + 2\,h\,u' + n^2\,u = \kappa_1 \sin \frac{2\,\pi\,t}{\tau_1} + m_1 \sin \frac{2\,\pi\,t}{\tau_2}$$

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but this equation and the general integral which corresponds to it can only be used until this wave is passed, that is for the values of t from 0 to τ_1; after this instant it is the second wave of the period, τ_2, which begins its action. The equation which corresponds to it is—

$$u'' + 2\,h\,u' + n^2 u = \kappa_2 \sin\frac{2\pi t}{\tau_2} + m_2 \cos\frac{2\pi t}{\tau_2}$$

This equation is to be used only during the τ_2 seconds which follow the first τ_1, and so on.

After the integration of every equation, the arbitrary constants are to be determined according to the corresponding initial conditions, that is, by the values of the angle of inclination u and of the angular velocity u' corresponding to the moments of the beginning of the action of every individual wave, and it is easily seen that this angle and this velocity depend not only on the "free," but on the "forced" oscillations also; and thus, by the variation of the values of the arbitrary constants, the terms containing the exponential factor are renewed after the passage of every wave, the free oscillations no longer extinguish, and the rolling appears to be non-uniform, consisting of the superposition of two sets of oscillations of different periods.

A numerical example will not leave any doubt on this subject.

Let us, for the sake of simplicity, suppose that κ remains constant and $m = 0$, then equation (58) will be—

$$u'' + 2\,h\,u' + n^2 u = \kappa \sin p\,t \qquad (58')$$

its general integral—

$$u = C_1 \,.\, e^{-ht}\cos n_1 t + C_2 e^{-ht}\sin n_1 t + M \sin p\,t + N \cos p\,t$$

where—

$$M = \frac{(n^2 - p^2)\,\kappa}{(n^2 - p^2)^2 + 4\,h^2 p^2}; \qquad N = -\frac{2\,h\,p\,\kappa}{(n^2 - p^2)^2 + 4\,h^2 p^2}; \qquad \text{and } n_1 = \sqrt{n^2 - h^2} \qquad (59')$$

and if the initial conditions are such that, for the moment—

$$t = 0, \qquad (u)_0 = \phi_0, \qquad (u')_0 = \omega,$$

then the constants C_1 and C_2 are—

$$C_1 = \phi_0 - N; \qquad C_2 = \frac{\omega + h\,(\phi_0 - N) - M\,p}{n_1} \qquad (61)$$

Let the period of the free oscillations of the ships be—

$$T_1 = 12''; \qquad \text{thus } n_1 = \frac{2\pi}{12} = 0{\cdot}5236,$$

and suppose $h = 0{\cdot}03$, then $n^2 = 0{\cdot}2751$, and if the wave slope Θ_0 be 9°, then $\kappa = \Theta_0 \,.\, n^2 = 2{\cdot}48°$. If we take first the regular system of waves, with the mean period $\tau = 8''$, to which corresponds the value of $p = \frac{2\pi}{8} = 0{\cdot}7854$, and for the initial conditions $\phi_0 = 0$ and $\omega = 0$, the formulæ (59′) and (61) give—

$$u = 0{\cdot}98° \,.\, e^{-0{\cdot}03t}\cos\frac{2\pi t}{12} + 10{\cdot}75°\, e^{-0{\cdot}03t}\sin\frac{2\pi t}{12} - 7{\cdot}12°\sin\frac{2\pi t}{8} - 0{\cdot}98°\cos\frac{2\pi t}{8} \qquad (62)$$

or otherwise—

$$u = 10{\cdot}79° \,.\, e^{-0{\cdot}03t}\sin\left(\frac{2\pi t}{12} + 5{\cdot}2°\right) - 7{\cdot}19°\sin\left(\frac{2\pi t}{8} + 7{\cdot}8°\right) \qquad (62')$$

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In order to obtain the oscillation of the ship on the second, third, fourth, &c., wave, we have only to put in this formula successively—

$$t = 8 + t_1, \quad t = 16 + t_1, \quad t = 24 + t_1, \quad t = 32 + t_1, \text{ &c.,}$$

and we shall obtain—

$$u_2 = 10{\cdot}79^\circ \cdot e^{-0{\cdot}24\, t_1} \cdot e^{-0{\cdot}03\, t_1} \sin\left(\frac{2\pi t_1}{12} + 245{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t_1}{8} + 7{\cdot}8^\circ\right)$$

$$= 8{\cdot}51^\circ\, e^{-0{\cdot}03\, t_1} \sin\left(\frac{2\pi t_1}{12} + 245{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t_1}{8} + 7{\cdot}8^\circ\right)$$

$$= -\,8{\cdot}51^\circ\, e^{-0{\cdot}03\, t_1} \sin\left(\frac{2\pi t_1}{12} + 65{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t_1}{8} + 7{\cdot}8^\circ\right)$$

For the sake of convenience I resume all these calculations in the following table :—

OSCILLATIONS OF A SHIP ON SUCCESSIVE REGULAR WAVES.

No. of the Wave.	Law of the Oscillations on the Wave.
1	$10{\cdot}79^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 5{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
2	$-\,8{\cdot}51^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 65{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
3	$6{\cdot}70^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 125{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
4	$5{\cdot}27^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 5{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
5	$-\,4{\cdot}15^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 65{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
6	$3{\cdot}26^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 125{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
7	$2{\cdot}57^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 5{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
8	$-\,2{\cdot}02^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 65{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
9	$1{\cdot}59^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 125{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
10	$1{\cdot}25^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 5{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
11	$-\,0{\cdot}98^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 65{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
12	$0{\cdot}78^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 125{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$
13	$0{\cdot}61^\circ\, e^{-0{\cdot}03\, t} \sin\left(\frac{2\pi t}{12} + 5{\cdot}2^\circ\right) - 7{\cdot}19^\circ \sin\left(\frac{2\pi t}{8} + 7{\cdot}8^\circ\right)$

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This table shows how rapidly the free oscillations diminish, and, after the passage of the thirteenth wave become practically insensible. For the sake of still greater clearness this table is represented graphically on the diagram (Fig. 1, Plate XXXIV.), on which the dotted line represents the evanescent free oscillations, the thin broken line forced ones, and the thick full line the resultant of the two. This diagram exhibits, as usual, the very well-known fact that the rolling is non-uniform so long as there exist free oscillations of a different period from the forced one.

Passing now to the consideration of the behaviour of the ship on the irregular waves of which the series (60) represents the successive periods, we shall have for the first wave—

$$\tau_1 = 8{\cdot}2'', \; p = \frac{2\pi}{\tau_1} = 0{\cdot}7662\,;$$

$$M = -7{\cdot}78^\circ\,; \qquad N = -1{\cdot}14^\circ\,; \qquad C_1 = +1{\cdot}14^\circ\,; \qquad C_2 = +11{\cdot}43^\circ\,;$$

and the oscillation is—

$$u = 1{\cdot}14^\circ e^{-0{\cdot}03t}\cos\frac{2\pi t}{12} + 11{\cdot}43^\circ e^{-0{\cdot}03t}\sin\frac{2\pi t}{12} - 7{\cdot}78^\circ\sin\frac{2\pi}{8} - 1{\cdot}14^\circ\cos\frac{2\pi t}{8}$$

$$= 11{\cdot}48^\circ e^{-0{\cdot}03t}\sin\left(\frac{2\pi t}{12} + 5{\cdot}6^\circ\right) - 7{\cdot}86^\circ\sin\left(\frac{2\pi t}{8} + 8{\cdot}7^\circ\right)$$

Taking the derivative of this formula, we have—

$$u' = 5{\cdot}96^\circ e^{-0{\cdot}03t}\cos\frac{2\pi t}{12} - 0{\cdot}90^\circ e^{-0{\cdot}03t}\sin\frac{2\pi t}{12} - 5{\cdot}96^\circ\cos\frac{2\pi t}{8} + 0{\cdot}93^\circ\sin\frac{2\pi t}{8}$$

and putting in these two formulæ $t = 8{\cdot}2''$ we obtain the inclination and the angular velocity, which are the initial conditions for the beginning of the action of the second wave. These are—

$$u = \phi_1 = \omega_1 = -9{\cdot}67^\circ\,; \qquad u' = -7{\cdot}21^\circ.$$

For the second wave we have by formulæ (59′) and (61)—

$$\tau_2 = 7{\cdot}7''\,; \quad p = \frac{2\pi}{\tau_2} = 0{\cdot}816\,; \quad M = -6{\cdot}24^\circ\,; \quad N = -0{\cdot}79$$

$$C_1 = -8{\cdot}88^\circ\,; \quad C_2 = -4{\cdot}52^\circ$$

Thus—

$$u = -8{\cdot}88^\circ e^{-0{\cdot}03t}\cos\frac{2\pi t}{12} - 4{\cdot}52^\circ e^{-0{\cdot}03t}\sin\frac{2\pi t}{12} - 6{\cdot}24^\circ\sin\frac{2\pi t}{7{\cdot}7} - 0{\cdot}79^\circ\cos\frac{2\pi t}{7{\cdot}7}$$

$$= 9{\cdot}96^\circ e^{-0{\cdot}03t}\sin\left(\frac{2\pi t}{12} + 243{\cdot}0^\circ\right) - 6{\cdot}29^\circ\sin\left(\frac{2\pi t}{7{\cdot}7} + 7^\circ\right)$$

$$= -9{\cdot}96^\circ e^{-0{\cdot}03t}\sin\left(\frac{2\pi t}{12} + 63^\circ\right) - 6{\cdot}29^\circ\sin\left(\frac{2\pi t}{7{\cdot}7} + 7^\circ\right)$$

As the time t is reckoned in this formula from the beginning of the action of this second wave, we take u', and, after putting $t = 7{\cdot}7''$, we obtain the initial conditions for the third wave, and so on.

Repeating the above calculation for the whole series, we obtain the following table :—

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OSCILLATIONS OF A SHIP ON AN IRREGULAR SYSTEM OF WAVES.

No. of the Wave.	Period of the Wave.	Law of the Oscillation on the Wave.
	Secs.	
1	8·2	$11{\cdot}48^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 5{\cdot}5^\circ\right) - 7{\cdot}86^\circ \sin\left(\frac{2\pi t}{8{\cdot}2} + 8{\cdot}7^\circ\right)$
2	7·7	$-\,9{\cdot}96^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 63^\circ\right) - 6{\cdot}29^\circ \sin\left(\frac{2\pi t}{7{\cdot}7} + 7^\circ\right)$
3	7·5	$8{\cdot}87^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 126^\circ\right) - 5{\cdot}75^\circ \sin\left(\frac{2\pi t}{7{\cdot}5} + 7^\circ\right)$
4	8·5	$5{\cdot}79^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 4^\circ\right) - 9{\cdot}11^\circ \sin\left(\frac{2\pi t}{8{\cdot}5} + 9^\circ\right)$
5	7·7	$-\,6{\cdot}53^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 48^\circ\right) - 6{\cdot}29^\circ \sin\left(\frac{2\pi t}{7{\cdot}7} + 7^\circ\right)$
6	8·5	$6{\cdot}35^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 67^\circ\right) - 9{\cdot}11^\circ \sin\left(\frac{2\pi t}{8{\cdot}5} + 9^\circ\right)$
7	7·5	$-\,4{\cdot}52^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 74^\circ\right) - 5{\cdot}75^\circ \sin\left(\frac{2\pi t}{7{\cdot}5} + 7^\circ\right)$
8	7·7	$3{\cdot}29^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 102^\circ\right) - 6{\cdot}29^\circ \sin\left(\frac{2\pi t}{7{\cdot}7} + 7^\circ\right)$
9	8·5	$5{\cdot}40^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 5{\cdot}5^\circ\right) - 9{\cdot}11^\circ \sin\left(\frac{2\pi t}{8{\cdot}5} + 9^\circ\right)$
10	7·5	$-\,8{\cdot}91^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 34^\circ\right) - 5{\cdot}75^\circ \sin\left(\frac{2\pi t}{7{\cdot}5} + 7^\circ\right)$
11	8·5	$9{\cdot}13^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 48^\circ\right) - 9{\cdot}11^\circ \sin\left(\frac{2\pi t}{8{\cdot}5} + 9^\circ\right)$
	8·5	$-\,7{\cdot}10^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 123^\circ\right) - 9{\cdot}11^\circ \sin\left(\frac{2\pi t}{8{\cdot}5} + 9^\circ\right)$
13	7·7	$-\,8{\cdot}59^\circ\, e^{-0{\cdot}03t} \sin\left(\frac{2\pi t}{12} + 5^\circ\right) - 6{\cdot}29^\circ \sin\left(\frac{2\pi t}{7{\cdot}7} + 7^\circ\right)$

This table shows that the free oscillations are no longer evanescent, and the diagram (Fig. 2, Plate XXXIV.), which represents graphically the same thing as the table, exhibits, in the clearest manner, the non-uniformity of rolling.

Mr. R. E. Froude in § 35 of his paper, "The Non-Uniform Rolling of Ships" (Trans. I.N.A., Vol. XXXVII.) says:—"The continual fresh disturbances due to the non-uniformity of swell avail effectively to maintain non-uniformity of rolling, in spite of the tendency of resistance to eradicate it." The above calculations give an illustration of this important statement, and show that the said non-uniformity of swell needs not to be a large one to produce a great effect.

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§ 14. We deduced the following two systems of equations of the motion of the ship on waves :—

$$\left.\begin{aligned}
\frac{V_0}{g}\cdot\frac{d^2\xi_0}{dt^2} &= -\frac{2\pi r}{\lambda_1}\left[B_0'\cos\frac{2\pi t}{\tau} - A_0'\sin\frac{2\pi t}{\tau}\right] - R\xi \\
\frac{V_0}{g}\cdot\frac{d^2\eta_0}{dt^2} &= -\frac{2\pi r}{\lambda_2}\left[B_0'\cos\frac{2\pi t}{\tau} - A_0'\sin\frac{2\pi t}{\tau}\right] - R\eta \\
\frac{V_0}{g}\cdot\frac{d^2\zeta_0}{dt^2}\,S\,\zeta_0 &= \psi\cdot S\,l + r\left[\left(a_0' - \frac{2\pi A_0'}{\lambda}\right)\cos\frac{2\pi t}{\tau} + \left(b_0' - \frac{2\pi B_0'}{\lambda}\right)\sin\frac{2\pi t}{\tau}\right] - R\zeta
\end{aligned}\right\} \quad (28)$$

and—

$$\left.\begin{aligned}
A\frac{d^2\theta_1}{dt^2} + P(r_0 - a)\,\theta_1 &= P(r_0 - a)\,\Theta_0\sin\alpha\left[N_1'\cos\frac{2\pi t}{\tau} - M_1'\sin\frac{2\pi t}{\tau}\right] - L_R \\
B\frac{d^2\psi}{dt^2} + P(R_0 - a)\,\psi &= P(R_0 - a)\,\Theta_0\cos\alpha\left[K_1'\cos\frac{2\pi t}{\tau} + L_1'\sin\frac{2\pi t}{\tau}\right] + g\rho S\,\xi_0 - M_R \\
C\frac{d^2\phi}{dt^2} &= -P\cdot\Theta_0\left[P_1'\cos\frac{2\pi t}{\tau} + Q_1'\sin\frac{2\pi t}{\tau}\right] - N_R
\end{aligned}\right\} \quad (41')$$

We have calculated the values of all the parameters contained in these equations; but, before giving the numerical results of their integration, we will consider that part of the general question of the late Mr. Wm. Froude, when he asked, "What is the *position of momentary equilibrium* for a body floating on a wave?"

To obtain these positions we have only to suppose in the above equation that all the terms containing the accelerations (the second derivatives) are zero, and that there is no resistance of water, as, by hypothesis, there is no relative motion of the ship on the wave for the positions of momentary equilibrium, and we see immediately that the first, the second, and the sixth equations cannot be satisfied by any value of the co-ordinates ξ_0, η_0, ζ_0, θ_1, ψ, ϕ, defining the position of the ship in space. This arises because these three equations do not contain terms which correspond to the stability of the ship, and urge her to take a definite position, and this fact is self-evident if the geometrical meaning of the variables ξ_0, η_0, and ϕ be remembered.

Respectively to the other three variables, which define the elevation of the centre of gravity above its natural level position ζ_0, and the angles of side inclination (θ_1), and of trim (ψ), there exists at every instant a definite value which satisfies the equation of momentary equilibrium, and these positions are represented on diagram (Plate XXXVI.) for the different head angles α. The meaning of the lines and letters being explained on the diagram itself, it needs no further explanation.

The equations (41') give also the values of the "accelerating forces which urge the ship to take the above momentary positions of equilibrium, if deviated from it," and thus they can serve to trace anything like the diagram of stability close to every one of these positions of equilibrium. But such a consideration of stability on waves would not be a complete one. In dealing with stability, it is not only necessary to have the value of the righting moment for every inclination, it is also useful to consider its rate of change, which is proportional to the metacentric height. Here, as our expressions are only approximate, the terms of second and higher orders being neglected, these terms, in the expression of the rate of increase of the righting moments, would give terms of the first order, and precisely these terms constitute the difference of stability on wave and on still water. Thus, to consider the stability on waves, we must have expressions of the moments exact to terms of the second order as to angles of inclination. But this would not be all—the ship is always in motion,

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and that must be taken into account. "Routh's Advanced Dynamics" contains all that is necessary for such a study, which is of a great practical interest, because, if great angles of inclination arise and an undamaged ship capsizes, it is surely not on still water.

This brief sketch of the subject of "stability on waves," as I understand it, shows its intricate character, so that this subject, with all the details which it merits by its importance, would require a paper still longer than the present one, and I delay it to another time.

§ 15. If we assume the resistance to be proportional to the first power of velocity, its effect will be to extinguish the free oscillation, and the forced ones remain almost unaltered—it is the same if there were no resistance—thus, for the heaving, pitching, and yawing we need only to consider the forced oscillations. For the rolling we must know the system of waves by which it is produced, because, as shown above, the cumulative action of a system of waves depends on the real succession of the waves and not only on their mean feature, which it is enough to know for the other constituents of the ship's oscillations, for which the resistance is comparatively great, and the free oscillations are extinguished as soon as formed. If such a system is not given, then we can apply the calculation of the "criterion amplitude" the method developed by Mr. R. E. Froude in the paper already mentioned. This criterion amplitude depends on the co-efficient of extinction adopted, and on the effective wave-slope, as also on the forced oscillation. We give therefore only this last, and to obtain their value we may neglect the resistance.

We shall consider three cases:—(1) The ship has no onward motion; (2) the ship has an onward velocity of 8 knots; and (3) her onward velocity is 10 knots.

For the first case it is convenient to compound into one the motions ζ_0 and η_0, and to put $\sigma_0 = \zeta_0 \cos \alpha + \eta_0 \sin \alpha$, then σ_0 will represent the horizontal oscillation of the centre of gravity of the body in the plane perpendicular to the crests of waves.

Then, remarking that $\tau^2 = \frac{2\pi\lambda}{g}$, we obtain

$$\sigma_0 = \frac{r}{V_0}\left[B_0' \cos\frac{2\pi t}{\tau} - A_0' \sin\frac{2\pi t}{\tau}\right]$$

and putting $\frac{Sg}{V_0} = n^2$ we have (the term $S\,l\,\psi$ being neglected in this approximation)—

$$\zeta_0 = r\left[m_0'' \cos\frac{2\pi t}{\tau} + n_0'' \sin\frac{2\pi t}{\tau}\right]$$

where—

$$m_0'' = \frac{n^2}{n^2 - \frac{4\pi^2}{\tau^2}}\left(a_0' - \frac{2\pi}{\lambda} A_0'\right); \qquad n_0'' = \frac{n^2}{n^2 - \frac{4\pi^2}{\tau^2}} n_0'.$$

For our case

$$r = 2{\cdot}5''' ; \qquad n^2 = 2{,}302 ; \qquad \tau = 9''.$$

The values of the co-efficients being calculated in §§ 8 and 9, we obtain immediately for σ_0 and ζ_0 the results given in the table below.

To calculate the pitching ψ, we remark that, putting

$$\frac{P(R_0 - a)}{B} = q^2.$$

We have obtained for the forced oscillation the formula—

$$\frac{q^2}{q^2 - \frac{4\pi^2}{\tau^2}} \omega_0 \cos\alpha \left[K_1' \cos\frac{2\pi t}{\tau} + L_1' \sin\frac{2\pi t}{\tau}\right]$$

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which can be used instead of the formulæ (59) when the co-efficient of resistance h is small in comparison with $q^2 - \frac{4\pi^2}{\tau^2}$, which is the case until the ship and the wave are not synchronous.

For our case $q^2 = 2{\cdot}16$ (as calculated in my paper on "Pitching," Trans. I.N.A., Vol. XXXVII.). $2h$ is nearly 0·26, and the difference between the above approximate and the true value is less than 2 per cent. of it.

In this manner we obtain the following table:—

FORCED OSCILLATION OF A SHIP ON WAVES. SPEED OF THE SHIP = 0.

	$\sigma_0 = a\cos\frac{2\pi t}{9} + b\sin\frac{2\pi t}{9}$		$\zeta_0 = c\cos\frac{2\pi t}{9} + d\sin\frac{2\pi t}{9}$		$\theta_1 = e\cos\frac{2\pi t}{9} + f\sin\frac{2\pi t}{9}$		$\psi = g\cos\frac{2\pi t}{9} + h\sin\frac{2\pi t}{9}$		$\phi = k\cos\frac{2\pi t}{9} + l\sin\frac{2\pi t}{9}$	
α	a	b	c	d	e	f	g	h	k	l
Deg.	M.	M.	M.	M.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
0	−0·09	−1·10	1·01	−0·18	0	0	−4·68	−0·22	0	0
11¼	−0·09	−1·14	1·11	−0·18	+0·44	−0·44	−4·70	−0·19	+0·66	−0·00
22½	−0·09	−1·23	1·20	−0·18	+0·85	−0·91	−4·68	−0·15	+1·27	−0·01
33¾	−0·09	−1·37	1·41	−0·18	+1·12	−1·36	−4·67	−0·01	+1·82	−0·03
45	−0·09	−1·58	1·68	−0·18	+1·36	−1·86	−4·55	+0·14	+2·08	−0·07
56¼	−0·07	−1·80	2·01	−0·17	+1·34	−2·68	−3·84	+0·35	+2·08	−0·13
67½	−0·04	−2·01	2·32	−0·12	+0·98	−3·12	−3·12	+0·56	+1·54	−0·19
78¾	−0·03	−2·11	2·45	−0·09	+0·69	−3·32	−1·97	+0·65	+1·20	−0·23
90	0	−2·18	2·58	0	0	−3·48	0	+0·75	0	−0·25
101¼	+0·03	−2·11	2·45	+0·09	−0·69	−3·32	+1·97	+0·65	−1·20	−0·23
112½	0·04	−2·01	2·32	+0·12	−0·98	−3·12	+3·12	+0·56	−1·54	−0·19
123¾	0·07	−1·80	2·01	+0·17	−1·34	−2·68	+3·84	+0·35	−2·08	−0·13
135	0·09	−1·58	1·68	+0·18	−1·36	−1·86	+4·55	+0·14	−2·08	−0·07
146¼	0·09	−1·37	1·41	+0·18	−1·12	−1·36	+4·67	−0·01	−1·82	−0·03
157½	0·09	−1·23	1·20	+0·18	−0·85	−0·91	+4·68	−0·15	−1·27	−0·01
168¾	0·09	−1·14	1·11	+0·18	−0·44	−0·44	+4·70	−0·19	−0·66	−0·00
180	0·09	−1·10	1·01	+0·18	0	0	+4·68	−0·22	0	0

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The period of the wave is 9″; the period of rolling 15″, hence $n^2 = \frac{P(r_0 - a)}{A} = \frac{4\pi^2}{225}$. The period of pitching is 4·27″, so that $q^2 = \frac{P(R_0 - a)}{B} = 2{\cdot}16$; and C = B = 318,000 met. t.

When the ship steams with any speed v, we must, instead of the true period τ of the wave, introduce into our formulæ the apparent one τ_1, calculated by the formula—

$$\tau_1 = \frac{\lambda}{\frac{\lambda}{\tau} - v\cos\alpha} = \tau\frac{\lambda}{\lambda - v\tau\cos\alpha}$$

and we shall obtain the following two tables :—

FORCED OSCILLATIONS OF A SHIP STEAMING 8 KNOTS. ELEMENTS OF THE SHIP AND WAVE THE SAME AS ABOVE.

		$\sigma_0 = a\cos\frac{2\pi t}{\tau_1} + b\sin\frac{2\pi t}{\tau_1}$		$\zeta_0 = c\cos\frac{2\pi t}{\tau_1} + d\sin\frac{2\pi t}{\tau_1}$		$\theta_1 = e\cos\frac{2\pi t}{\tau_1} + f\sin\frac{2\pi t}{\tau_1}$		$\psi = g\cos\frac{2\pi t}{\tau_1} + h\sin\frac{2\pi t}{\tau_1}$		$\phi = k\cos\frac{2\pi t}{\tau_1} + l\sin\frac{2\pi t}{\tau_1}$	
α	τ_1	a	b	c	d	e	f	g	h	k	l
Deg.	S.	M.	M.	M.	M.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
0	12·70	−0·18	−2·20	0·89	−0·16	0	0	−4·13	−0·19	0	0
11¼	12·59	−0·17	−2·22	0·98	−0·16	2·94	−2·94	−4·15	−0·17	+1·30	−0·0
22½	12·25	−0·17	−2·27	1·07	−0·16	3·05	−3·28	−4·17	−0·13	2·35	−0·02
33¾	11·85	−0·16	−2·37	1·27	−0·17	3·30	−4·02	−4·22	−0·01	3·15	−0·04
45	11·27	−0·14	−2·47	1·55	−0·17	3·14	−4·30	−4·15	+0·13	3·37	−0·11
56¼	10·75	−0·10	−2·56	1·87	−0·17	2·52	−5·04	−3·54	+0 32	2·96	−0·18
67½	10·17	−0·05	−2·55	2 21	−0·12	1·50	−4·72	−2·95	+0·33	1·93	−0·24
78¾	9·60	−0·03	−2·40	2·38	−0·09	0·85	−3·85	−1·90	+0·62	1·38	−0·25
90	9·00	0	−2·18	2·58	0	0	−3·48	0·0	+0·25	0	−0·25
101¼	8·55	+0·03	−1·90	2·52	+0·09	−0·59	−2·85	+2·03	+0·67	1·08	−0·23
112½	8·10	+0·03	−1·62	2·48	+0·13	−0·73	−2·30	+3·38	+0·61	1·25	−0·19
123¾	7·75	+0·05	−1·34	2·21	+0·19	−0·87	−1·74	+4·30	+0·39	1.54	−0·15
135	7·50	+0·06	−1·09	1·92	+0·20	−0·79	−1·08	+5·50	+0·16	1·44	−0·09
146¼	7·30	+0·06	−0·89	1·66	+0·21	−0·60	−0·73	+5·70	−0·01	1·18	−0·04
157½	7·13	+0·05	−0·77	1·44	+0·22	−0·44	−0·46	+5·70	−0·18	0·80	−0·02
168¾	7·05	+0·05	−0·69	1·33	+0·22	−0·22	−0·22	+5·75	−0·23	0·41	−0·01
180	7·00	+0·05	−0·66	1·21	+0·22	0	0	+5·80	−0·26	0	0

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It must be remembered that the absolute path of the centre of gravity of the ship in space is, when it steams and oscillates, a spiral-formed line, the co-ordinates σ_0 and ζ_0 define the position of the C.G. of the ship on a vertical plane moving uniformly with the ship's speed, remaining parallel to itself and perpendicular to the crest of waves.

FORCED OSCILLATIONS OF THE SAME SHIP STEAMING 10 KNOTS.

		$\sigma_0 = a\cos\frac{2\pi t}{\tau_1} + b\sin\frac{2\pi t}{\tau_1}$		$\zeta_0 = c\cos\frac{2\pi t}{\tau_1} + d\sin\frac{2\pi t}{\tau_1}$		$\theta_1 = e\cos\frac{2\pi t}{\tau_1} + f\sin\frac{2\pi t}{\tau_1}$		$\psi = g\cos\frac{2\pi t}{\tau_1} + h\sin\frac{2\pi t}{\tau_1}$		$\phi = k\cos\frac{2\pi t}{\tau_1} + l\sin\frac{2\pi t}{\tau_1}$	
a	τ_1	a	b	c	d	e	f	g	h	k	l
Deg.	S.	M.	M.	M.		Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
0	14·05	−0·22	−2·70	0·88	−0·16	0	0	−4·07	−0·19	0	0
11¼	13·9	−0·22	−2·75	0·97	−0·16	4·90	−4·90	−4·13	−0·17	1·59	0·0
22½	13·5	−0·20	−2·77	1·06	−0·16	6·40	−6·85	−4·16	−0·14	2·35	−0·02
33¾	12·8	−0·18	−2·79	1·26	−0·16	5·50	−6·18	−4·20	−0·00	3·70	−0·06
45	12·05	−0·16	−2·85	1·51	−0·16	4·50	−6·15	−4·15	+0·13	3·75	−0·12
56¼	11·25	−0·11	−2·81	1·85	−0·15	3·02	−6·05	−3·55	+0·32	3·25	−0·20
67½	10 5	−0·05	−2·75	2·20	−0·11	1·67	−5·30	−2·95	+0·52	2·10	−0·26
78¾	9·7	−0·03	−2·45	2·32	−0·09	0·88	−7·25	−1·90	+0·62	1·39	−0·27
90	9·0	0·0	−2·18	2·58	0	0	−3·48	0	+0·75	0	−0·25
101¼	8·4	+0·03	−1·84	2·57	+0·09	−0·57	−2·73	+2·05	+0·67	−1·04	−0·20
112½	7·9	+0·03	−1·55	2·55	+0·03	−0·67	−2·12	+3·43	+0·61	−1 19	−0·15
123¾	7·5	+0·05	−1·24	2·30	+0·19	−0·80	−1·60	+4·44	+0·40	−1·44	−0·09
135	7·2	+0·06	−1·00	2·00	+0·22	−0·72	−0·98	+5·56	+0·16	−1·32	−0·04
146¼	6·9	+0·05	−0·81	1·75	+0·22	−0·54	−0·65	+5·84	−0·01	−1·08	−0·02
157½	6·80	+0·05	−0·70	1·52	+0·23	−0·38	−0·41	5·95	−0·18	−0·22	−0·01
168¾	6·66	+0·05	−0·63	1·41	+0·22	−0·19	−0·19	6·15	−0·25	−0·36	0·00
180	6·62	+0·05	−0·59	1·31	+0·22	0	0	6·20	−0·29	0·00	0

These two tables and the diagrams, on which the same results are represented, show graphically, in the clearest manner, the behaviour of a ship in a seaway, when her course and speed vary. It must be remembered, as above explained, that the rolling angle never does consist of the forced oscillations only, the free one existing always, because the waves are never uniform. The

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amplitude of the free oscillations may be 1·5 times, or twice as large as that of the forced ones; it depends on the actual succession of the waves, and can only be calculated when the actual not uniform systems of waves are given. Other methods for this calculation are explained in the paper of Mr. R. E. Froude "On Non-Uniform Rolling." This paper being inserted in the Transactions of this Institution, these methods need not be repeated here.

§ 16. Mr. W. Froude terminated his paper "On the Rolling of Ships" by the following words: "When a new ship is sent to sea her constructor has to watch her behaviour in a seaway with as anxious and uncertain an eye as if she were an animal he had bred and was rearing and hoped would turn out well; not a work he had himself completed, and whose performance he could predict in virtue of the principles he had acted on in its design." The principal aim of my investigations has been to show methods serving to calculate in a complete manner the behaviour of a ship on a given state of the sea. It is evident that these methods are quite sufficient to solve all the questions which arise regarding the influence on the sea-going qualities of a ship, of changes in the distribution of loads on board, changes of trim, &c.

DISCUSSION.

The following remarks on Captain Kriloff's papers, by Professor A. G. Greenhill, F.R.S. (Associate), were read: I feel much disappointment that an official engagement prevents me from attending the reading of Captain Kriloff's two valuable papers. The author has developed the mathematical theory in a very clear and elegant manner, and we shall attend with great interest the appearance of the complete treatise promised us, of which these papers form a first instalment. As a matter of scientific history, it is peculiarly appropriate that the theory of the strains of a ship, first discussed by the celebrated Euler nearly 150 years ago, in the Petersburg Transactions, should receive its fullest development from a professor of the Russian Naval Academy. I am pleased to have an opportunity of endorsing the eloquent quotation from Fourrier as to the absolute need of proceeding to a numerical result before it can be claimed that the theory is completely understood. But it is the common experience of mathematical instructors, with which Captain Kriloff obviously agrees, that nothing is so difficult as to persuade a student to work out a numerical exercise; he considers it a waste of time and derogatory to his powers, although he rarely succeeds in obtaining a result anything resembling the true one, especially if the answers are not given—an omission very much disliked by the student. With the practical man it is different; he must work to some unknown result, and he will previously test the formulæ by an application to well-known cases, for fear of a misprint. I attribute this reluctance to numerical computation to the use of seven figure logarithms, and to a disregard of the relative importance of digits. Captain Kriloff has done well to give his numerical results to three figures only, that is, to within 1 per cent., amply sufficient when we consider the variations of texture of the materials used in naval architecture. The theoretical reasoning in the paper concerning the Smith effect in altering the buoyancy of a given small displacement of water, raises the question again concerning the paradoxical effect of the apparent loss of stability on the top of a wave. If the floating body—a small one relatively to the length of the waves—partakes of the vertical motion, so that the displacement remains unchanged, then the stability conditions should remain the same, all acting forces being changed in the same ratio.

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Perhaps this question will receive adequate consideration in the discussion. It suggests a useful direction for experimental research with models on a small scale. Professor Hele-Shaw has shown us what valuable information can be obtained concerning stream lines which completely baffle mathematical analysis, by his ingenious apparatus; and I would suggest that Captain Kriloff should set some of his students to work to study his theories in an experimental tank of mercury, and to watch the behaviour of solid iron model vessels in an artificially generated procession of waves, employing iron floating on mercury with the idea of reducing the influence of friction to a comparison with actual conditions.

Mr. R. E. Froude, F.R.S. (Associate Member of Council): My Lord and Gentlemen, I quite agree with the encomiums passed by Professor Greenhill, in the letter which we have just heard read on the subject of this paper, and I think that Captain Kriloff has done a great work in thus systematising the mathematical theory of the motions of a ship on waves. When I speak of systematising, if I were to be understood to mean that this paper does no more than systematise theoretical investigations which have been already made, I should do injustice to it, because, although, so far as I follow the paper, one cannot say that there are any absolutely novel propositions deduced, yet propositions already known are placed on a strictly formal and orthodox mathematical basis, which hitherto, perhaps, we have been content to rest rather upon common-sense illustrations. The treatment of the paper determines the complete motion of a ship, either at rest, or steaming in any direction relatively to any regular system of waves; and the peculiar characteristic of the paper, perhaps, is this (as compared with previous investigations, so far as my reading extends), that it takes into account all the motions of the ship—the heaving, and the three rotational motions, the rolling, the pitching, and the yawing—and considers them from the very outset as existing in combination and conjunction, in their right and necessary relative phases and relations. And, although it does that, although it considers these motions in conjunction, yet, so far as I follow the treatment, it is possible for anyone who wishes to consider either one of the motions alone to, so to say, detach the portion of the solution which refers to that particular motion from the rest by simply putting certain of the values as equal to 0. But, in the working, the whole of the forces that are involved in the separate motions are considered in conjunction, and that feature of the paper suggests to me an interesting question as to whether we really gain by that mode of treatment, or whether we lose anything by it, as compared to what has hitherto been the usual treatment of considering each of these kinds of motions separately, as generated by those components of the wave's system which affect these motions. Now, as to that point, I should wish Captain Kriloff to enlighten us on one matter which I do not feel perfectly certain about from my study of the paper. So far as I can follow the paper, I gather that, having regard to the nature of the approximations which are used, the combined motion which is determined by the investigation is nothing else but the combination of those separate motions, which you would determine by taking the components of the wave forces separately into account. If that is the case, then it appears that we do not gain in the matter of accuracy by taking all the motions into account in conjunction. And the question then is, whether we gain or lose on any other ground. I suppose myself that that depends very much upon the student. I suppose there are a good many students—and I should think Captain Kriloff's pupils will be among them—to whom an investigation of this kind would be more compendious, at any rate, and perhaps more in keeping with their natural way of examining problems, than the separate investigation of the separate motions. The students I am speaking of now are those to whom the study of analytical geometry in three dimensions is a familiar mode of thought. There are a good many other people, with whom I must class myself, to whom the

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consideration of all the motions in conjunction from the first is, I must confess, what I should incline to call a gratuitous addition to the difficulties of the subject. It appears to me possible also that the considering the motions in conjunction, instead of separately, hampers one, or may hamper one, in the choice of those simplifying assumptions which are desirable in order to bring the subject conveniently within the reach of mathematical treatment. Very simple assumptions may be perfectly legitimate for some of the motions, and more intricate and laborious ones necessary for the treatment of others. So far as I follow the paper, one simplifying assumption which is made here is that the ship is what we sometimes call an ironing box, that is, that her form is cylindrical about a vertical axis. That is a very legitimate assumption in a general way, but I do not know that it is more generally legitimate than what has hitherto been the usual assumption, or at least a very common assumption, and is far more convenient, namely, that the ship is an isochronous oscillator. The two assumptions mean the same thing at small angles, but at larger they do not. According to the nature of the ship one or either of them might be the more correct. I should say that, on the average, there is no reason for supposing that this particular assumption made in the paper is more correct than that the ship is an isochronous oscillator. The assumption that the ship is an isochronous oscillator has this convenience: that you are at once able to express the motion of the ship in terms simply of period of the ship, without taking account of her shape; at least you only have to take the characteristics of the shape of the ship into account in order to obtain what M. Bertin calls the reduction co-efficients, that is, the qualifying co-efficients which you are to apply to the apparent wave slope in order to obtain the actual moment of rotation which the water exerts upon the ship. Now, with regard to this reduction co-efficient—the study, in fact, of what we are accustomed to call the effective wave slope—I do not think that Captain Kriloff quite correctly represents the position that my father occupied in his first investigation. I do not think that the difficulty that my father found in determining the effect of a trochoidal wave arose from his not at that time knowing the structure of the wave, but was simply that he did not see his way to introducing the trochoidal wave into the mathematics, so as to give him an integral equation. Professor Rankine attacked the same problem, and worked it out, and brought out an integrable equation, but only by making the assumption that the height of the wave was infinitesimal, which was rather cutting the Gordian knot. I think my father felt that where Rankine had failed he was not likely himself to succeed. That is one reason why he dropped the study of that branch of the subject, and I think he also saw what I think Captain Kriloff found in his study of the pitching, that, practically, the assumption that the wave was sinusoidal was quite good enough. My father afterwards made a very close investigation into the effective wave slope, which he published in a paper addressed to this Institution, and also in a magazine article in *Naval Science*. I do not know whether Captain Kriloff has studied that paper, but I should very much like to know, if he has, how he considers that the treatment of that paper bears upon his own mathematics. I must confess that, at the present moment, I should not be prepared to pass an examination in that investigation of my father's. I have rather forgotten the details of it, but I know it took into account the variations of the pressure of the trochoidal wave in all parts, and the local actions of these pressures on all parts of the sections of a ship. I do not think that my father obtained any equation which he could integrate for the whole surface of the ship. He did not see his way to do that, but he arrived at certain rather remarkable and paradoxical conclusions for some extreme proportions of ship with regard to the difference of the righting moment from that of the apparent wave slope. Another point which has to do with that is this. It seems to me that, perhaps it may be said, it is waste of time to study very minutely the effect of the trochoidal wave structure upon the oscillation of ships, on this ground, that the trochoidal wave, although it is a possible form, when once started, is

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not now held to be the true ocean wave. It is supposed that ordinary waves are much more closely represented by the wave of Professor Stokes, which agrees with the trochoidal wave under the same conditions as the trochoidal wave agrees with the sinusoidal wave; all become sinusoidal waves when the height is small relatively to the length. I am under the impression that, when you get large heights and really steep waves, the "Stokes" wave differs as much from the trochoidal as it does from the sinusoidal. I am not certain about that, but it does seem clear that, if you take the trouble to investigate the effect of very steep waves, assigning them the precise characteristics of the trochoidal as opposed to the sinusoidal wave, you may be wasting your time. As bearing partly on the same subject, I should like to ask Captain Kriloff a question with regard to the two tables in the Appendix on pages 171 and 172. The difference between the results of the two tables is said to be that, in the second table, the progressive diminution of the radii of the generating circles of the wave is taken into account. Captain Kriloff points out that, by taking that into account, very large differences, and in some cases very important differences, are produced. I should like to know what assumptions the two tables may be broadly said to respectively correspond with. I am not quite clear whether, for instance, the first table corresponds with the statement on page 148 of the Appendix, that "Our first approximation corresponds not only to the theory of Mr. W. Froude, but includes the principal reductions of M. Bertin, especially if we take for the profile of our set of level surfaces, not the sinusoidal, which corresponds to the trochoid of the free surface of water, but to the trochoid passing through the ship's centre of buoyancy." I do not quite follow whether the first table is for the sinusoidal which corresponds with the trochoid of the free surface of water, and the second table for that which corresponds with the trochoid passing through the ship's centre of buoyancy, or whether it includes a closer approximation than that. Now, again referring to the allusion to my father's paper by Captain Kriloff, he says, with regard to the effect of oblique waves, that, in my father's paper, "the assumptions are of such an arbitrary character that it is impossible to judge of the degree of such an approximation." Now I was struck with the character of this diagram (Plate XXXIII.), which shows that, when the ship has no speed the angle of forced oscillation of the ship is, apparently, closely proportional to the sine of the head angle. As far as I recollect, that, practically, was precisely what my father's assumption in his paper amounted to. The assumptions in my father's paper appear, therefore, to be justified by the result. There are so many interesting points in the paper that it is impossible to refer to them all, but I cannot conclude without referring to the very beautiful illustration of the effect of an almost imperceptible irregularity of wave system to convert uniform rolling into exceedingly irregular rolling. I must also allude to the beauty of this diagram (on Plate XXXIII.), illustrating so very graphically and completely the effect of steaming at various speeds and in various directions relatively to the sea, upon the oscillations.

Professor J. H. Biles (Member of Council): My Lord and Gentlemen, unfortunately I have not had the opportunity of reading this paper carefully through, and I am in no position to say anything that can contribute with advantage to this discussion, I am afraid; but, I should like to take the opportunity of saying how grateful I am to Professor Kriloff for having followed up so fully and so ably the point he brought before us when he gave his last paper. This paper, or, as he calls it, a memoir (it is really a memoir), I think is one of the most remarkable we have had in this Institution. It is one which attempts, and which I suppose attempts successfully, to deal with the complete motion of a ship in a seaway. Mr. Froude has very clearly pointed out that there are certain disadvantages accompanying the treatment of the complete solution; but there are, as he also pointed out, great advantages

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in the complete solution, and to us, personally, I think the great advantage is that, though we have had a comparatively complete solution of oscillation in one direction of motion, up to the present we have not had a solution in any other direction, so that we are now in a very much better position. We can reduce the equations that Professor Kriloff has produced from a motion in three dimensions to a motion in any one direction. To that extent we are now much better off than we were before. Another great advantage, and an advantage which appeals to everybody, I am sure, is that Captain Kriloff has, at a great deal of trouble, and great expenditure of time, given us a numerical example, or examples, which will be a guide to a great many who, I am afraid, would be utterly unable from the mathematics of the solution to make any use of the paper at all. To those who are studying the subject of shipbuilding and naval architecture in a more or less practical way, any contribution of this kind which enables, not only those who are trained experts to make use of this paper, but the ordinary staff of a drawing-office to make use of it, I think is of enormous value, and I take it that, perhaps beyond its scientific value to us, the greatest value it has is the practicability of its application. There is one thing I asked Captain Kriloff before when we had this subject under discussion, and I am not sure he has dealt with it in this paper. If not, perhaps he would say something about it in his reply. What is the effect upon the wave structure of the intrusion of a ship into it? How is that likely to modify the supporting forces that come upon a ship?

Sir WILLIAM WHITE, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): My Lord and Gentlemen, it would be a very poor compliment to Captain Kriloff to assume that, from a hasty perusal of this paper, we could adequately discuss it. It is a paper which requires close study. In its range of treatment it is the boldest and most thorough attempt that has yet been applied to this problem of the movement of a ship in a seaway. On the mathematical side we have Professor Greenhill's authority, regarding it as a very excellent and correct piece of work. We did not need to be assured of its correctness, knowing Captain Kriloff's powers as a mathematician. But Captain Kriloff would be the first to admit that, to bring this problem under the power of mathematical treatment, assumptions must be made, and (as Mr. Froude has well pointed out) the practical value of the paper will be governed largely by the substantial accuracy of these assumptions. It is not possible, so far as I am aware, for Captain Kriloff, or any mathematician, to answer a question like that which Professor Biles has asked. There is an old proverb about looking into a stone wall and knowing what is inside. We are getting towards that sort of introspection by methods which have been recently devised, and perhaps, in some future age, a Captain Kriloff of that time, with the aid of a method corresponding to the Röntgen rays, will inspect what is happening in the interior of a wave structure when a solid body is intruded. But most people, when these circumstances occur at sea, have not the opportunities, some of them have not the disposition, to make that inquiry. My interest in this subject of the mathematical treatment of the motion of ships at sea goes back now more than thirty years. I have had the advantage of reading most that has been written upon the subject, not merely in that time, but, so far as I could trace, in the times that went before, and I would certainly say that, in nothing that I have seen as yet published, has there been so comprehensive an attempt to deal with the whole problem as we have in this paper. When we come to its application to practice, I take it that Captain Kriloff, in the main, confirms the principles upon which we have been working since the late Mr. Froude gave us his classical paper on this subject. That is to say, the guiding principles for naval architects laid down by Mr. Froude in relation to securing steadiness of platform at sea are entirely confirmed by Captain Kriloff's more complete investigation. There is nothing, so far as I am aware—no result which he has reached—which throws any doubt upon the principle that the ship

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which has the longest still-water period will, on the whole, be the steadiest at sea. It confirms also the practical conclusion that we do well to utilise fluid resistance, in order to diminish range of rolling. These, I take it, are the main results of scientific inquiry as applied to modern practice in ship designing, and there is nothing in Captain Kriloff's paper that in the least interferes with our confidence in those rules. We cannot forecast what conditions of sea may be met with. It is impossible to represent mathematically the endless variety of conditions that will occur. But, I am bound to say that, in my judgment, for practical purposes, the process of graphic integration based upon experimental procedure, which was proposed and so successfully applied by the late Mr. Froude, is that which has the greatest value. In saying that, I am not in the least minimising the value of purely mathematical inquiry. As I said before, the difficulty is, at the outset, to establish assumptions which would enable mathematical processes to be applied, and to make those assumptions in a form that approximates sufficiently to the conditions of practice. We are under the greatest obligation to Captain Kriloff for honouring us with this communication. The Transactions of the Institution of Naval Architects contain the best work on this subject available to the student, and, in giving us this paper, Captain Kriloff has added a worthy piece of work to the many good pieces of work which have been before published.

Captain A. KRILOFF (Associate): My Lord and Gentlemen, I must express my most grateful thanks for Sir William White's kind words, and to Mr. Froude and Professors Biles and Greenhill, and beg your pardon, gentlemen, for the mutilation of the English grammar and English pronunciation which you have heard. I will try to do what I can in giving the explanations which have been required. In dealing with application of mathematics to physical questions, the first thing is to state precisely what are the assumptions made. I have made only a single assumption; it is the one which is stated at the top of the 148th page. "The single hypothesis which is necessary for our theory is the same as that made to treat the pitching; the pressure which acts on the ship in every point of her submerged surface is that which takes place in the corresponding point of the wave, supposed trochoidal." As to this last part of the hypothesis, I have taken the trochoidal wave because it is the most simple one. The method used in my previous paper can be applied in the same manner to any kind of wave you like. It may be the Stokes wave, it may be the translational wave of Scott Russell, it may be the heaving wave of Mr. Guyou—for every wave for which you have the analytical expression of its dynamical structure the method there developed applies. This method is based on quite other considerations than those before used in "Naval Architecture." The method used there, and also in this paper, is taken from "Celestial Mechanics and Theoretical Astronomy." It is the method of successive approximations. In answer to the question of Mr. Froude, I start from quite exact mathematical equations. Then to simplify them we must make simplifying hypotheses; but, if we make such hypotheses without calculation, we cannot have any quantitative valuation; because, if we simplify anything, if we neglect anything, we must clearly show that, what we have neglected to indicate, we had the right to neglect, and that what we have neglected was really small in comparison with that which we have retained. The whole study of this paper is only intended to show that we could neglect all these quantities, and that the motion of the ship can be treated separately in its component parts. If we had assumed it *à priori*, we should not know if we could make it or not, or that we could neglect certain quantities, because the theory of the motion of a solid body shows that the rotational motions about different axes have an influence on one another, and therefore it was necessary to show that this influence is of the second order of magnitude. The second order of magnitude is to be understood thus: If we have, say, an angle of 10°, that is an absolute value of $\frac{1}{6}$th, what we neglect is

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the square of this. It is $\frac{1}{36}$th, it is then an angle of 1¼. If we only have to deal with angles not exceeding 10°, this is sufficient; but if we have greater angles—if we require a study of rolling up to 20°—then it would be necessary to consider the second approximation in all the formulæ, and to retain the squares of the angles of inclinations. It would require another paper quite as long as this to explain the development of this second approximation, to show how this approximation is to be obtained. And with every approximation the formulæ will become more and more complicated; for an example I can mention the theory of the moon: to calculate the place of the moon with an exactitude of nearly a second of arc it is required to calculate 2,652 times, so that you cannot ask from an astronomer, "Calculate me the exact place of the moon for to-day by the general formulæ"—he can only answer after two weeks. But it would be necessary to calculate only forty or fifty terms to have the moon's place up to 10″ or 12″, and only five to have its place up to 10′: this is an example of how rapidly the complication of the formulæ increases when you wish to obtain the utmost exactitude, and therefore we have to stop immediately after the practically sufficient result is obtained, and this is given by our first approximation, and by the second, if we need to examine the stability of a ship on waves. There is a second simplifying hypothesis which Mr. Froude has mentioned, it is that I have taken the ship as a right-sided solid. Yes, right-sided, but only close to the load waterline; this simplification was illustrated in my paper on pitching, and I have shown a simple manner of studying the influence of the departure of the real form of the ship from perpendicularity, and I have shown there that the corrections which it involves are very small, and can practically be neglected. If we have to make a special study of this subject; for instance, if we have to study what are the differences in the seagoing qualities of a ship, when we change her form in a certain manner, this can be done in the manner shown at the end of my paper on pitching. In respect to the question of Professor Biles with regard to considering the influence of a body on the wave structure itself, that is a question which I believe will not soon be solved, for there is not a single case in hydrodynamics where this question has been attacked and solved. I am extremely pleased by Professor Greenhill's approval of the mathematics of my paper, and of the necessity of making all the calculations in shipbuilding with three figures instead of the usual practice with seven figure logarithms, and ten or twelve in the cubes of ordinates. I cannot explain how it is possible that this evidently useless and enormous waste of time is retained in practice. Experiments with heavy metallic models on mercury would perhaps be a good laboratory work, but in St. Petersburg we have an experimental tank, where some experiments on the oscillations of ships have been already performed, and where others will be undertaken; therefore, I could hardly recommend to my students to work with such costly and dangerous material as mercury. In terminating my remarks I must express my grateful thanks to the Council for the honour I have had in reading this paper before this Institution.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I feel rather like the west-country yokel who, when he was asked on coming out of church by one of the churchwardens, "What did you think of the sermon?" (the preacher, I should mention, was a very brilliant one) said, "It was magnificent; but it is not for a poor man like me to understand it." Nevertheless, I ask you to give a very hearty vote of thanks to Captain Kriloff for the valuable contribution he has made to our proceedings this year.

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ON STRESSES EXPERIENCED BY A SHIP IN A SEAWAY.

By Captain A. Kriloff, I.R.N., Professor at the Naval Academy at St. Petersburg; Associate.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, April 1, 1898; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

This paper will contain an application of the results obtained in my paper, "A General Theory of the Oscillations of a Ship on Waves," to the estimate of those additional stresses which proceed from the heaving and pitching of the ship, and from the differences of the wave and the hydrostatical pressures. The necessity for this estimate is expressed in the quotation which I made in the introduction to the above paper from Sir E. Reed's memoir, and, as this subject has been several times summarised and sketched in its historical development before this Institution by such authorities as Sir E. Reed, Professor Biles, and others, I need not repeat these summaries, and I pass directly to my subject.

§ 1. The process of the calculation of stresses experienced by a ship in a seaway acquires a higher degree of neatness if decomposed into its elementary parts.

When a ship is in equilibrium on still water her structure is strained; when on waves, to this strain additional ones are to be added, these are: (1) Stresses arising from change of support, parts of the ship being immersed in and others emerged out of water, the whole ship being considered in equilibrium on the crest or bottom of the wave, the pressure of which is considered as hydrostatical. This is the principal part of the additional stresses, and is computed by the well-known process of Sir E. Reed. (2) To the above must be joined the additional stress arising from the difference of the wave and the hydrostatical pressures (Smith's correction). (3) To these two are to be joined stresses arising from the heaving and pitching motions of the ship. These last stresses arise from two causes: (*a*) The ship in motion takes, on the waves, positions which are different from her positions of equilibrium; (*b*) the ship's motion not being rectilinear and uniform, the forces of inertia (reactions against accelerations) are not zero, and give place to stress in the structure. I will confine myself to a detailed treatment of this last part of the additional strains conjointly with the second one, and I will give only a few remarks simplifying the calculation of the first. These remarks will appear as self-evident and well-known to those who have

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themselves performed these calculations; but they will, perhaps, be useful to young engineers and students, when they have to deal with this matter for the first time.

§ 2. When, nine years ago, as pupil at the shipbuilding section of the Naval Academy at St. Petersburg, I had to perform these calculations for the first time, I felt a certain difficulty, which I had to overcome myself, because I could not find in any text-book, or periodical, complete and full indications for the method of performing these calculations without waste of time and labour. To be clear, what I required and could not find were such net, precise, and mathematically elaborated indications for all the details of the process such as I possessed in dealing with astronomy and deviation of compasses during my previous service.

Then, applying the general principles of numerical calculations, I elaborated that system of shipbuilders' calculations, in which I used Tchebyscheff's rule for the quadratures, and which I afterwards published in No. 4 of the "Bulletin de l'Association Technique Maritime." This system Sir William White did me the honour to mention at the Jubilee Congress as the "Russian method."

§ 3. The first thing we need to have is the curve showing the distribution of weights. The calculation of this is the hardest part of the work. The only indications how to make it which I could find were but the repetition of Sir E. Reed's words: "The total length has been divided into 20 ft. spaces . . . for each division the weight of the hull and the weight of the equipment has been determined." With the sole change of the perfect into the imperative, it seemed to me that this passage ought not to be understood *verbatim*, and I adopted the following method. The weights were subdivided into three categories:—

(1) Weights continuously distributed over the whole length of the ship, *e.g.*, the outer skin with its framing, decks, &c.

(2) Weights continuously distributed over a part of the total length of the ship, as side armour, engines, boilers, coal, ammunition and stores, small-bore artillery, &c.

(3) Concentrated weights, armour-clad transverse bulkheads, sternpost and rudder, large guns, &c. It is self-evident that the distribution of the whole of the weights of the first category over the length of the ship will be represented by a continuous curve, extending from stem to stern; to draw this partial curve with sufficient accuracy we need only a few ordinates (6 or 8) equally distributed. The calculation of each of these ordinates, specification in hands, is very easily performed, because each of them represents the weight of 1 ft. length of the part of the structure under consideration. For the framing the weight of a transverse frame at the place corresponding to that of the ordinate being computed, it is to be divided by the distance between the frames in feet. Thus calculating the ordinates for every particular weight

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and drawing the corresponding partial curve always from the preceding one, we shall obtain a line which represents the total distribution of the weights of the first category. This curve, as well as all the intermediate ones, will be continuous.

The distribution of the weights of the second category cannot be represented by a continuous curve extending from stern to bow over the whole length of the ship, but the distribution of every particular weight will be figured by a continuous curve—in the majority of cases even by a straight line—extending over the length occupied by the weight considered. The superposition of these partial curves, the construction of which is very easy, the weights and their longitudinal distribution being known, will give a curve arranged in steps. This last curve being superposed on the first, we shall obtain also a step-shaped line, representing the distribution of weights of the first two categories. The steps can be then adjusted, observing only that the area remains unaltered. The weights of the third category, if represented on the same scale as the preceding two, would give ordinates extending far outside the limits of the drawings; they need not be represented in this way, but it is simpler to reckon them as exterior forces applied at the corresponding points.

The construction of the curve of support on still water cannot present any difficulty.

On the curve of effective loads, obtained by the curve of weights and of support, the concentrated weights will also be represented as exterior forces, they will only be introduced into the curve of the shearing stress, which is obtained either by graphical or numerical integration of the curve of effective loads; at the places of application of the concentrated weights there will be steps numerically equal to the corresponding forces. A second integration gives the curve of moments, which will be a continuous one as to ordinates, but not as to curvature, having angular points at the places of application of the concentrated weights. When the calculations are performed in this way they will be found, I cannot say agreeable, but surely not deterrently tedious.

§ 4. Passing to the ship on a wave, in Sir E. Reed's equilibrium hypothesis, the first thing we have to do is to find such a position of the ship on the crest or bottom of the wave. Here, also, no indication is to be found how to make it in the simplest way, and I have often heard from engineers that it is an operation requiring a great deal of work. It seems that the two symbolical drawings, Figs. 14 and 15, of Sir E. Reed's paper were considered as an indication, to use first the elevation of the ship, to draw a position of the wave on this plan, and to calculate the corresponding displacement, and then to shift the wave profile up and down until the true displacement is obtained.

There is a calculation equivalent to the above, but which when properly arranged can be performed in a very simple manner, requiring barely ten minutes' work. I permit myself to describe it here.

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One of the most useful principles of numerical calculations is the following: "If the value of a variable quantity, which differs but little from a known constant one, is required, it is not this value itself which must be directly calculated, but its difference from the said constant." Therefore, in our case, for whatever may be the position of the ship on the wave, we must directly calculate, not the displacement itself, but only its variation contained between the load-water line and the surface of the water. In order to make it, draw the level line A B of the wave, and take the ordinates corresponding to the section of the ship. If these are Tchebyscheff's, then take for them, but if equidistant, then for these equidistant lines (the number of which need not be greater than ten or twelve for the whole length of the ship) a little strip of paper, mark on it the level line and the ordinates of the wave surface, numbering them in the same way as the corresponding cross-section of the ship; from this strip mark on the *body* plan the positions of the wave surface for every cross-section, when its level plane coincides with the load-water line of the ship, draw the corresponding ordinates, and make the following calculation:—

No. of the Section.	Ordinate at the L.W.L.	Ordinate at the Surface of the Wave.	Height of the Immersed (+) or Emerged (−) Area.	Immersed (+) or Emerged (−) Area.
No.	a	b	c	$(a+b)c$.
0	$\frac{1}{2}a_0$	$\frac{1}{2}b_0$	c_0	$\frac{1}{2}(a_0+b_0)c_0$
1	a_1	b_1	c_1	$(a_1+b_1)c_1$
2	a_2	b_2	c_2	$(a_2+b_2)c_2$
3	a_3	b_3	c_3	$(a_3+b_3)c_3$
4	a_4	b_4	c_4	$(a_4+b_4)c_4$
5	a_5	b_5	c_5	$(a_5+b_5)c_5$
6	a_6	b_6	c_4	$(a_6+b_6)c_4$
7	a_7	b_7	c_3	$(a_7+b_7)c_3$
8	a_8	b_8	c_2	$(a_8+b_8)c_8$
9	a_9	b_9	c_1	$(a_9+b_9)c_9$
10	$\frac{1}{2}a_{10}$	$\frac{1}{2}b_{10}$	c_0	$\frac{1}{2}(a_{10}+b_{10})c_{10}$
Sum		S		V

Correction $\epsilon = \frac{V}{S}$.

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If the sum V—which is proportional to the difference of the initial displacement of ship and that which she has in the assumed position on the wave, *i.e.*, when her L.W.L. coincides with the level plan—be zero, the assumed position would be the required one. If V differs from zero, the level line of the wave is to be raised (when V is positive), or lowered (when V is negative), by the quantity $\epsilon = \frac{V}{S}$. Placing now the level line of the wave above or beneath the L.W.L. on the calculated distance ϵ, and repeating the same calculation, we obtain either V = 0, or a very small second correction ϵ_1, which will give the required position of the ship on the wave.

When making this second calculation, it is sometimes convenient, for large partial areas, to draw an auxiliary ordinate between the two, and use Simpson's rule. Then, in the last column of the above schedule, we should have, instead of $(a_i + b_i)\, c_i$, the quantity $\frac{a_i + 4\, b_i' + b_i}{6}\, c_i$, where b_i' is the auxiliary ordinate.

The calculation will be simplified if the ordinates and heights be expressed, not in feet, corresponding to the scale of the drawings, but in their real length on the drawing in millimetres, or $\frac{1}{16}$ in., then ϵ will be obtained in the same units.

It may be observed that, to place a ship by this method in the position of equilibrium on the crest or bottom of a wave we need not know her displacement. We have not calculated the angle of trim, so that the centre of buoyancy and the ship's centre of gravity will not be on the same vertical line; it is better to introduce the corresponding correction in the curve of moments, although it could easily be made in an analogous manner as above.

To the position thus determined, the Smith correction is to be applied, if it is desired to take the difference between the hydrostatical and the hydrodynamical wave pressure. The process of Mr. Smith is fully explained in his paper, and requires no other indications.

The equilibrium position being found, we have only to represent graphically the additional support proceeding from the immersed or emerged areas, and on Smith's correction, and this curve being twice integrated gives the additional shearing stresses and bending moments, if considered statically.

I will now pass to the dynamics of our subject.

§ 5. It is self-evident that the rolling and the yawing and the horizontal components of the general heaving motion have but a secondary influence on the additional stresses, which are mostly due to the vertical component of the heaving, and to the pitching motions, and thus we have only to consider these two.

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Let a ship steam at a given angle across a system of regular waves at any speed at which it is required to investigate the additional stresses (to those acting on still water) which her structure has to experience.

To make this investigation, we consider four positions of the ship on the waves, the positions corresponding to the instants t equal to 0, $\frac{\tau_1}{4}$, $\frac{\tau_1}{2}$, $\frac{3\tau_1}{4}$, τ_1 being the apparent period of the wave, and the instant 0 corresponding to the passage of the bottom of the wave through the middle plan of the ship. The analytical expressions of the pitching angle ψ and the ordinate ζ_0 of the ship's centre of gravity being previously obtained, as shown in my other paper; for each of these instants we calculate the position of the ship occupied on the wave, her angular acceleration ψ'' and the vertical component ζ_0'' of her translational acceleration, then, to obtain the additional stress, we have only to draw the representative curve of the additional effective loads. (Support is to be considered as a negative load.)

For every section these additional loads consist of (1) change of support proceeding from the change of the immersed area of the ship's cross sections; this is immediately calculable, the position of the ship on the wave being determined. (2) Difference of hydrodynamical wave support from the hydrostatical one. This can be constructed strictly by Mr. Smith's method, or with sufficient approximation by multiplying the immersed area by $\frac{2\pi r}{\lambda}\cos U$, where r is the describing radius of the wave ($2r$ = its height), λ its length, and U the phase—

$$U = 2\pi\left(\frac{x}{\lambda_1} - \frac{t}{\tau_1}\right),$$

x being the abscissa of the section considered, $\lambda_1 = \frac{\lambda}{\cos a}$, the effective length of the wave a being the head angle of the ship reckoned from the direction of the course of the wave. (3) Forces of inertia (reactions against acceleration), these bearing to the whole weight of the section considered the same ratio as the corresponding acceleration to the acceleration of gravity. To calculate these forces we must remember that the positive values of x belong to the bow, the value of ψ is positive when the bow is raised, and the positive values of ζ_0 are reckoned downwards; thus the principal part of the vertical component of the acceleration at the section corresponding to the abscissa x is $\zeta_0 - \psi''.x$, and thus, if P denotes the corresponding ordinate of the curve of weights (all included), the additional re-action against acceleration is

$$-P.\frac{(\zeta_0 - \psi''.x)}{g}$$

the signs are to be taken algebraically, a final negative value denoting an apparent diminution of weight.

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The sum of the corresponding ordinates of the three curves thus calculated separately will give the resultant distribution of the additional effective loads on the wave, and this curve being twice integrated will give the additional shearing stresses and the additional bending moments.

This process being performed for the four positions of the ship on the wave at the instants—

$$t = 0, \quad t = \frac{\tau_1}{4}, \quad t = \frac{\tau_1}{2}; \quad t = \frac{3\tau_1}{4},$$

that which Sir Edward Reed has so well called the "wave of strain" which rolls over the structure of the ship can be determined.

Indeed the bending moment M_x at the section x is a periodical function of the time t having the period τ_1, thus it can be expanded in a Fourrier's series of the form—

$$M_x = A_0 + A_1 \cos \frac{2\pi t}{\tau_1} + B_1 \sin \frac{2\pi t}{\tau_1} + A_2 \cos \frac{2\pi t}{\tau_1} + B_2 \sin \frac{4\pi t}{\tau_1} + \ldots .$$

here A_0 is the stress on still water, and having the values of M_x corresponding to the above values of t, we immediately obtain the values of the co-efficients A_1 and B_1, A_2 and B_2 (these two will generally be very small and can be neglected), then the general expression of M_x will be—

$$M_x = A_0 + A_1 \cos \frac{2\pi t}{\tau_1} + B_1 \sin \frac{2\pi t}{\tau_1}$$

The co-efficients A_1 and B_1 will vary from one section to the other, according to a law which can be represented either graphically, or with a very good approximation, by the analogous Fourrier's expressions—

$$A_1 = a_0 + a_1 \cos \frac{2\pi x}{l} + b_1 \sin \frac{2\pi x}{l} + a_2 \cos \frac{4\pi x}{l} + b_2 \sin \frac{4\pi x}{l} + \ldots .$$

$$B_1 = a_0' + a_1' \cos \frac{2\pi x}{l} + b_1' \sin \frac{2\pi x}{l} + a_2' \cos \frac{4\pi x}{l} + b_2' \sin \frac{4\pi x}{l} + \ldots .$$

where a_0, a_1, b_1, a_2, b_2 . . . are independent of x, and only functions of the head angle α and elements of the wave, l denoting the whole length of the ship.

Thus an analytical expression of the variation of the stresses experienced by a ship can be formed, but the process, as described above, is a rather complicated one to obtain.

The mathematical part is developed, with some details, in the Appendix to this paper, and a numerical example is given to illustrate the process; but, to make it easier of application to practice it is necessary to give simple analytical expressions containing only the dimensions of the ship and the elements of the wave, and giving, with a sufficient approximation, the pitching and heaving of the ship on this wave, and the stresses produced, for an ideal distribution of loads. I have formed such

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approximate expressions, but I have not yet verified their degree of approximation by a sufficient number of numerical examples relating to ships of different degrees of fineness. When these tedious numerical calculations are terminated, I shall hope to have the honour of presenting their results to this Institution.

APPENDIX.

The formulæ and schedules referred to are contained in my paper, "A General Theory of the Oscillations of a Ship on Waves."

§ 1. In my paper, "A General Theory of the Oscillations of a Ship on Waves," I gave the general equations of the motion of a ship in a seaway. These equations enable us to calculate not only the positions taken by a ship on the wave, but to know also the accelerations of every point of it, and thus to investigate the stresses experienced by a ship with a greater degree of approximation than by other methods hitherto given. I will shortly explain here how such a calculation can be performed.

§ 2. Let us consider the ship occupying at any instant the corresponding position on the wave. This position is characterised by the values of the absolute co-ordinates ξ_0, η_0, ζ_0 of the ship's centre of gravity, and by the three angles θ_1, ψ, ϕ, the notations being the same as in the paper mentioned above, in which the expressions of all these six quantities as a function of the time t are established. To calculate the stress (shearing force and bending moment) at any given section of the ship, corresponding to the abscissa value a, we have only to take the algebraical sum of the components, parallel to the ship's Z axis, of all the forces acting on her, and situated at one side of the section considered, say, the bow side (abscissa value $x = \mathrm{L}$), and the sum of the moments of these forces about the neutral axis of the section C D.

Thus we shall have:

$$\text{Shearing force} \qquad \mathrm{S} = \int_{\mathrm{CBD}} \mathrm{Z}\, d\,v \tag{1}$$

$$\text{Bending moment} \quad \mathrm{M} = \int_{\mathrm{CBD}} \Big[(z - c)\,\mathrm{X} - (x - a)\,\mathrm{Z} \Big] d\,v \tag{2}$$

where $x = a$, $z = c$ are the equations of the neutral axis of the section C D, and the summation relates to all the forces acting on the volume C B D contained between C D and the bow B.

The forces acting on the part considered are :—

(1) The gravity of weight.

(2) The forces of inertia (reactions against accelerations).

(3) The hydrodynamical wave pressure.

(4) The resistance of water.

In calculating the effect of these forces I shall confine myself to the same approximation as in the above paper, *i.e.*, that the second and higher powers of the angles θ_1, ψ are neglected. Here, only

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the angle of pitching ψ is of importance; it is generally less than 6° or 7°, or in absolute measure $\frac{1}{10}$, so that its square is less than $\frac{1}{100}$.

Then for gravity we had the following expressions of the components on the ship's axes:—

$$X = -\psi g; \qquad Y = \theta_1 g; \qquad Z = g,$$

and, denoting by S^1 and M_1 the corresponding parts in the expressions of the shearing stress and bending moment, we shall have—

$$S_1 = g \int_{CBD} d v = \int_{CBD} P \, d x \tag{3}$$

where P denotes the weight per foot of length and

$$M_1 = \int_{CBD} \Big[(z - c) X - (x - a) Z \Big] d v = -\psi \int_{CBD} (z - c) P \, d x - \int_{CBD} (x - a) P \, d x \tag{4}$$

it is easy to conclude that the expression $\int (z - c) P \, d x$ is very small by itself, and, being multiplied by the factor ψ, it can be neglected in comparison with the second term, thus it can be simply written—

$$M_1 = -\int_{CBD} (x - a) P \, d x \tag{4'}$$

These two expressions show that, in spite of the inclination of the ship, the stress proceeding from the weight can be calculated in the same manner as if the ship were in the upright position of equilibrium.

(2) The force of inertia is measured by the product of the mass of the particle considered multiplied by its acceleration, and the direction of this force is inverse to that of acceleration.

In every treatise on theoretical mechanics the following complete expressions of the components of the acceleration of the points, the co-ordinates of which are $x\ y\ z$, in respect to axes moving with the body, are to be found—

$$\left.\begin{aligned}
w \cos \overset{\wedge}{(w\ x)} &= \xi_0'' a + \eta_0'' a_1 + \zeta_0'' a_2 + z q' - y r' + p (p x + q y + r z) - x \omega^2 \\
w \cos \overset{\wedge}{(w\ y)} &= \xi_0'' b + \eta_0'' b_1 + \zeta_0'' b_2 + x r' - z p' + q (p x + q y + r z) - y \omega^2 \\
w \cos \overset{\wedge}{(w\ z)} &= \xi_0'' c + \eta_0'' c_1 + \zeta_0'' c_2 + y p' - x q' + r (p x + q y + r z) - z \omega^2
\end{aligned}\right\} \tag{5}$$

where ξ_0'', η_0'', ζ_0'' are the components of the acceleration of the origin O of the axes $o\ x$, $o\ y$, $o\ z$ (in our case it is the ship's C.G.) on the axes fixed in space; $a, a_1 \ldots c_2$ are the cosines of the angles between the two sets of axes; p, q, r are the components of the angular velocity ω on the axes $o\ x$, $o\ y$, $o\ z$ and p', q', r', the components of angular accelerations, *i.e.*, the derivatives of p, q, and r in respect to the time t. Before substituting these complete expressions in the formulæ (1) and (2), we can simplify them, confining ourselves to the degree of approximation adopted. Thus the terms $p (p x + q y + r z)$ and $x \omega^2$ and their analogues in the other two equations are of the second order in respect to the angular velocity, which is small, and thus in the first approximation these terms can be neglected. The terms $\eta_0'' a_1$ and $\xi_0'' a_2$ are also of the second order, because the cosines a_1 and a_2 are of the first order, and η_0'' and ξ_0'' are also small quantities (it must be understood that the

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ratios $\frac{\xi_0''}{g}$ and $\frac{\eta_0''}{g}$ are small, in our case they are less than $\frac{1}{7}$), thus we shall have the following approximate formulæ, it being remarked that—

$$p' = \frac{d^2\theta_1}{dt^2} = \theta_1''; \quad q' = \frac{d^2\psi}{dt^2} = \psi''; \quad r' = \frac{d^2\phi}{dt^2} = \phi''.$$

$$\left.\begin{aligned} w \cos(\overset{\wedge}{w x}) &= \xi_0'' + z\psi'' - y\phi'' \\ w \cos(\overset{\wedge}{w y}) &= \eta_0'' + x\phi'' - z\theta_1'' \\ w \cos(\overset{\wedge}{w z}) &= \zeta_0'' + y\theta'' - x\psi'' \end{aligned}\right\} \qquad (5')$$

the schedule (9′) for the cosines being used. Then there will be obtained for the shearing stress and bending moment arising from forces of inertia—

$$\left.\begin{aligned} S_2 &= -\int_{CBD}(\zeta_0'' + y\theta_1'' - x\psi'')\,dm = -\frac{\zeta_0''}{g}\int_{CBD} P\,dx - \theta_1''\int_{CBD} y\,dm + \frac{\psi''}{g}\int_{CBD} x\,P\,dx \\ &= \frac{1}{g}\left(\psi''\int_{CBD} x\,P\,dx - \zeta_0''\int_{CBD} P\,dx\right) = \frac{\psi''}{g}\int_{CBD}(x-a)\,P\,dx + \left(\frac{a\psi''}{g} - \zeta_0''\right)\int_{CBD} P\,dx \end{aligned}\right\} \qquad (6)$$

the sum $\int_{CBD} y\,dm = 0$, and the reason of the last transformation being that the value $\int_{CBD}(x-a)\,P\,dx$ is easily calculated graphically by the very well-known process, and—

$$\begin{aligned} M_2 &= -\int_{CBD}\left[(z-c)(\xi_0'' + z\psi'' - y\phi'') - (x-a)\left(\zeta_0'' + y\theta_1'' - x\psi''\right)\right]dm \\ &= -\frac{\xi_0''}{g}\int_{CBD}(z-c)\,P\,dx + \frac{\zeta_0''}{g}\int_{CBD}(x-a)\,P\,dx - \frac{\psi''}{g}\int_{CBD}(z-c)\,z\,P\,dx + \frac{\phi''}{g}\int_{CBD}(z-c)\,y\,P\,dx \\ &\quad + \theta''\int_{CBD}(x-a)\,y\,dm - \frac{\psi''}{g}\int_{CBD}(x-a)\,P\,dx \end{aligned}$$

remarking that—

$$\int(z-c)\,P\,dx$$

is small, and

$$\int(z-c)\,y\,dm = \int(x-a)\,y\,dm = 0,$$

and that the integral—

$$\int(z-c)\,z\,P\,dx$$

will be small if compared with—

$$\int(x-a)\,x\,P\,dx,$$

except for sections close to the extremities of the ship. But for these sections the bending moments need not be calculated at all; we shall have the following expression for the principal value of M_2—

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$$M_2 = \frac{\zeta_0''}{g}\int_{CBD}(x-a)\,P\,dx - \frac{\psi''}{g}\int_{CBD}(x-a)\,x\,P\,dx$$

$$= -\left(\frac{\psi''.a}{g} - \frac{\zeta_0''}{g}\right)\int_{CBD}(x-a)\,P\,dx - \frac{\psi''}{g}\int_{CBD}(x-a)^2\,P\,dx \qquad (7)$$

These two expressions show that the stresses produced by inertia are the same as if, at every section x, an additional weight be added, bearing to that which is really in this section the ratio of the corresponding acceleration—

$$\left(\psi'' x - \zeta_0''\right)$$

to the acceleration of gravity g.

The last transformation is only made as giving a simple mode of graphical calculation. It may also be remarked that—

$$\frac{1}{g}\int_{CBD}(x-a)^2\,P\,dx$$

is the moment of inertia of the bow part of the ship in respect to the plan of the considered section C D.

The former result could be anticipated *à priori*, because the addition of the above-mentioned weight is equivalent to replacing the real weight by the apparent one, and it is the apparent one which acts when the ship is in motion, the mathematical expression being only established to show clearly what was neglected to obtain it.

(3) To compute the wave-support, we could use the expressions (31), and, transforming them successively, we should obtain the expression of resultant support, and of its moment as a function of the time t. These expressions would involve certain parameters analogous to (41), the summation extending, not from stern to bow, but only from the section considered to the bow. But it is simpler to obtain another equivalent expression better adapted to graphical calculation. To represent the position of the ship on the wave it is sufficient to draw the intersection of her longitudinal plan with the wave (effective wave profile) and the ship's load W.L. To make it we need only calculate the values ξ_0, η_0, ζ_0, corresponding to the instant considered; these would give the position of the ship's C.G.; the value of ψ — will give the inclination of the ship, and to have the profile of the wave, we must only remark that, at the moment $t = 0$, the bottom of the wave passes through the plane $\eta_0\,\zeta_0$.

We need only to calculate the difference of the support in the considered position of the ship on the wave, and on still water. This difference is due: (1) to the emergence or immersion of parts of the ship contained between her natural load waterline and the wave surface. To represent it graphically we need only calculate the additional immersed or emerged areas for a sufficient number (ten to twelve) sections of the ship. Let these areas be denoted by σ.

(2) To the difference of the waves and the hydrostatic pressure. The corresponding difference in support can either be obtained in an exact manner, shown by Mr. Smith, or, with a sufficient degree of approximation, by neglecting the progressive variation of the radii of the describing circle, and taking the wave support in the same ratio to the hydrostatical as the length of the normal to the trochoid to the radius of its rolling circle. It is as—

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$$\left(1 + \frac{2\pi r}{\lambda} \cos U\right) : 1.$$

The approximation will be still closer, if we take for the radius r, not its value on the surface, but its value corresponding to the immersion of the ship's centre of buoyancy; that is, if we put—

$$r = \frac{h}{2} \cdot e^{-\frac{2\pi c}{\lambda}},$$

where h is the height of the wave and c the immersion of the ship's C B.

In these formulæ U is the phase corresponding to the section considered—

$$U = 2\pi \left(\frac{x}{\lambda_1} - \frac{t}{\tau_1}\right)$$

and—

$$\lambda_1 = \frac{\lambda}{\cos \alpha},$$

α being the head angle of the ship and τ_1 the apparent period of the wave.

Thus we have only to take the curve representing the distribution of the hydrostatical support and to multiply its ordinates Ω by the corresponding value of—

$$\frac{2\pi r}{\lambda} \cos U;$$

we thus obtain the curve representing the additional correction, *i.e.*, the difference of the wave and the hydrostatic support.

The corresponding shearing stress and bending moments will be—

$$S_3 = -\int_a^L \sigma \, dx - \frac{2\pi r}{\lambda} \int_a^L \Omega \cos U \, dx \qquad (8)$$

$$M_3 = -\int_a^L (x - a) \, \sigma \, dx - \frac{2\pi r}{\lambda} \int_a^L (x - a) \, \Omega \cos U \, dx \qquad (9)$$

or, if we put for graphical representation—

$$y = \sigma + \frac{2\pi r}{\lambda} \Omega \cos U \qquad (10)$$

then—

$$S_3 = -\int_a^L y \, dx \qquad (8')$$

and—

$$M_3 = -\int_a^L (x - a) \, y \, dx \qquad (9')$$

to which expressions the graphical integration is immediately applicable.

(4) To calculate the effect of resistance of water we must make some hypothesis as to its law, but for fine ships this effect can be neglected, and for flat bottomed ships it can be assumed to be the

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same as for a plane having the form of the load-line, then it can be approximately calculated in a simple manner when the resistance is proportional to the first power of the velocity, or to its square. For our case of a fine ship we have not to consider it at all, and I shall not write down the formulæ corresponding to the various hypotheses.

§ 3. Summarising the above results, we see that the additional stresses on the wave are—

$$\left.\begin{aligned} S &= S_2 + S_3 \\ M &= M_2 + M_3 \end{aligned}\right\} \qquad (10)$$

where S_2, S_3, M_2, M_3 have the expressions (6), (7), (8'), (9').

These expressions can be calculated in two different manners :—

(1) We can either calculate all these quantities apart and then take their sums; or

(2) We can calculate the sums without calculating the constituents separately.

The first process requires the calculation of the values—

$$\int_a^L P\,dx, \qquad \int_a^L (x-a)\,P\,dx, \qquad \text{and} \int_a^L (x-a)\,x\,P\,dx, \qquad \text{or of} \int_a^L (x-a)^2\,P\,dx \qquad (11)$$

where P is the ordinate of the curve of weights. When these three quantities are computed for all the values of A (graphically) the stresses produced by inertia can be immediately obtained when the law of motion of the ship is known. To obtain S_3 and M_3 we draw the curve—

$$y = \sigma + \frac{2\pi r}{\lambda}\,\Omega \cos U,$$

corresponding to the values—

$$t = 0, \qquad t = \frac{\tau_1}{4}, \qquad t = \frac{\tau_1}{2}, \qquad t = \frac{3\tau_1}{4}$$

and after a double integration of it, we obtain the four systems of values of S_3 and M_3; as these are periodical functions of the time t, we can easily calculate the co-efficients of the corresponding Fourrier's series as explained in the paper itself, and thus obtain a representation of the action of the wave.

The second process is explained in the paper itself.

DISCUSSION.

Mr. Archibald Denny (Member of Council): My Lord, I do not intend to say much on this paper. I think I am, perhaps, a little responsible for it in one way, because I asked Captain Kriloff last year to be good enough to give us something we could apply to practice. I did not pretend I was sufficiently mathematical to follow all the work; but I said, "If you will give us something that a mild mathematician, like myself, could deal with, we should be extremely grateful to you." I think he has done that in this paper. Captain Kriloff will not, I am sure, think I am criticising any of his

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methods if I suggest to him that, instead of his calculation on page 200, he should simply use the tons per inch curve. The tons per inch vary so little—the curve so nearly approximates a straight line—that I think you would get the position of a wave traced on the side of a ship quite easily. The way we do it in our own office is to draw down an approximate wave, and then calculate the displacement. Captain Kriloff thinks it is not necessary to do that, but we find it is a convenient way, and if the displacement is not quite correct you can alter it from the tons per inch curve. Also, instead of correcting the diagram of moments, we correct the wave profile. Before starting you get the position of the centre of gravity of the displacement, and, if it corresponds with the centre of gravity of the ship, there is an end of it. I am extremely disappointed that Captain Kriloff has not managed to give us the example, but I know he will publish it afterwards, and I am sure the Institution owes a debt of gratitude to him. I would like to say (Sir William White mentioned it before) that we are deeply indebted to our foreign members for many abstruse investigations of this matter, and perhaps this year we have more papers from our foreign members than ever before. We lack not in this country gentlemen who are able to make original research of this kind, but there is one thing I think our nation is extremely good at, namely, that once they get hold of the right end of abstruse calculations they can generally put them into practice.

Professor J. H. Biles (Member of Council): My Lord and Gentlemen, this plan of Captain Kriloff of arriving at the adjustment of the supporting forces is an admirable one, and has been used by others. I am sure Captain Kriloff is aware of it, though the thing has not been published. It is quite an obvious thing to take the difference between the supporting forces in the vicinity of the water-line and treat them as the change, and not again treat the whole calculation for displacement. Especially that is so in making calculations for several conditions of load that are approximately close to each other. I cannot quite agree with Mr. Denny that it is simpler to go over the whole displacement.

Mr. Denny: That was the first case I was referring to.

Professor Biles: In the first case it naturally must be done; but, after that, having once got the under-water form calculated, you have done what is really the most difficult part of the work, and the variation that takes place in the vicinity of the water-line, due to the wave profile, is comparatively simple. It is very kind of Captain Kriloff to have put it into his paper in such a good form, and to have brought it to the notice of members who, possibly, may not have made use of such a method, but who will, when they understand it, see how much more simple is that method than the ordinary one of beginning at the beginning. That, however, is quite aside from the main object of this paper. I, with Mr. Denny, and with all the members of this Institution, regret very much that we have only had from Captain Kriloff the work and the amount of labour he has shown, but that we have not had the results of that labour in a practical form. I should be very glad to give Captain Kriloff some cases that I had where the weight curves had been exceedingly carefully worked out, and where a great deal of work has been done in finding the stress upon a ship in conditions of waves of various heights and various lengths, and various positions of ships in relation to the wave crest, skew positions across the line of the crest of the waves, and also the inclined position of the ship in relation to its own vertical. Perhaps I may express it in this way. Suppose that a series of parallel lines represent a series of crests of the waves—then the vessel has been placed at a series of angles—say, in relation to the wave crest, and also in the wave when in that skew position. The vessel has been inclined to the vertical, so that there is a great deal of information and work for that particular ship

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which may be of use to Captain Kriloff, and it would be exceedingly interesting to the members of this Institution if he would work out by this method the stresses that would come upon the ship, so that we might have them compared with the older and more laborious method. I offer that as a suggestion, and any information I have of that kind is quite at Captain Kriloff's disposal. I know from experience in doing work of this character that there is a great amount of labour involved in it.

Mr. Macfarlane Gray: Was it statically or dynamically?

Professor Biles: This is purely statical, with Smith's corrections. The pressure due to the wave structure is taken account of in all cases; not the supposed heaving up of the water; but that the water itself is in motion, but not the ship. That is what I understood Mr. Macfarlane Gray to mean when he asked about the condition. The vessel is supposed to be instantaneously at rest on a wave with the ordinary wave structure. The work of these calculations is very great. The stresses that come upon a ship have been determined in several cases, and I should very much like to have the results compared with those by Captain Kriloff's method. Of course, that is only, after all, a comparison for a vessel in one position of motion, because this is instantaneously at rest, but all the advantages of Captain Kriloff's doing the work in this particular vessel will be that we shall have an extension of it into the cases where the vessel is in motion, and we shall have some confirmation of it in the particular cases, or the particular point of the motion, when the motion is zero. It is an advantage to make the calculations, which he has promised to give us, upon vessels on which calculations, of a kind which are continuous with that, have been previously made. Perhaps Mr. Denny may have some special vessels of that kind which he can give to Captain Kriloff, and other members may also have some, so that we should have before us, not a vessel taken out of the dark, so to speak, with which we are not familiar, but vessels with which we are familiar, and upon which work of the old kind has been done already.

Mr. J. I. Thornycroft, F.R.S. (Vice-President): I only rise to say that it appears to me the Institution is greatly indebted to Captain Kriloff for what he has brought before us. I believe it is a step in advance, and that although, apparently, it only deals with a vessel on waves of a somewhat symmetrical character, still we may estimate, from what is proved when the motion of the ship is taken into account, to some extent what takes place when in an irregular system of waves which cause shocks to the ship, and it is possible that, from the method Captain Kriloff has taken, by estimating what is left out, we may, by making assumptions of compound waves, be able to realise the conditions where the ship is, apparently, struck by the wave, and when the forces it is subjected to in simple waves are greatly increased. I am very glad to see that, at the end of the paper, Captain Kriloff promises to give us a detailed calculation.

Sir William White, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): I quite endorse all that has been said as to the great value of the paper. When we are dealing with this subject we should never forget a man who, in modern times, was the originator of most of what has been done, the late Professor Rankine. The methods described in the paper as "Sir Edward Reed's hypotheses" are Rankine's. They are fully described in the "Treatise on Shipbuilding" which he edited, and it was following Rankine's lead (as I can say in the absence of Sir Edward Reed) which led to the adoption of a hypothetical wave form equalling the ship's length, and of a reasonable height in relation to its length. Dr. Young, the author of the undulatory "Theory of Light," was asked by the Admiralty in the early part of this century to consider the question of the strains on, and the stresses supported by ships, and he then tried to pass from the condition of still water to that of wave motion on somewhat

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similar lines. But Rankine deserves the chief credit. So that, in honouring, as we do, the memory of Rankine, I am sure we shall have Captain Kriloff's concurrence in saying that we should substitute "Rankine's hypotheses" for the phrase "Reed's hypotheses" used in the paper.

Captain A. KRILOFF (Associate): My Lord and Gentlemen, Mr. Denny has criticised the method developed on page 200. I have not read this page, because it takes more time to read it than to perform the calculation described. To place the ship in the position of equilibrium on a given wave when we have the drawings of the ship does not require more than ten minutes of time to perform. You will immediately see that it is so, because you have only to take twenty ordinates, and then to make ten multiplications of small numbers—mentally, of course—and then to make an addition—that is the whole process. This requires only a few minutes to do, and, applying the ordinary way, I believe it will be almost impossible to calculate the displacement of a ship in ten minutes.

Mr. DENNY: You are quite correct, my criticism was not sound.

Captain KRILOFF: I accept with my most grateful thanks the proposition of Professor Biles, because it will give, not only a comparison of the results, but also an example, for a type of ship, of what you want, and therefore I will do all that I possibly can to elaborate this in the most complete manner, after I have obtained from Professor Biles the necessary drawings and the previous results of his calculations. Mr. Thornycroft asked if I had well understood the action which Sir Edward Reed names the percussive shocks of the waves on the ship. I cannot say precisely, because I cannot calculate it completely, but it seems, from some calculation, that such percussive shocks are of great influence on local strains, and not in the general distribution of strains over the whole ship. We had an example of the action of such percussive shocks on the unfortunate ship, the *Livadia*, during her first voyage from England to Spain. The effects were described in the Transactions of this Institution, and show clearly powerful local action. In concluding my reply, I feel it to be an agreeable duty to express my thanks for the welcome that my papers have received in this Institution.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): We have already expressed our thanks for the first paper, but I am sure you will all desire me to move a vote of thanks to Captain Kriloff for his extreme kindness in giving us the benefit of his great mathematical knowledge and careful investigation. I would therefore ask you for a vote of thanks to Captain Kriloff for the paper he has just given us.

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THE PROBLEM OF STABILITY IN NAVAL ARCHITECTURE.

By Herr L. Gümbel, of Berlin.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, April 1, 1898; Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President, in the Chair.]

More has been written and spoken on the subject of stability than on any other problem connected with shipbuilding. It may, therefore, seem somewhat superfluous if I ask such an important assembly to lend me, for a few minutes, a friendly ear while I speak on this subject.

The general conditions of equilibrium of a body under the action of any forces, when the body, as well as the points of application of the forces P, are situated in a system of rectangular co-ordinates x_0, y_0, z_0, are (see Fig. 1, Plate XLVI.)—

$$\text{I.} \quad \Sigma\,(X) = 0.$$
$$\text{II.} \quad \Sigma\,(Y) = 0.$$
$$\text{III.} \quad \Sigma\,(Z) = 0.$$

That is to say, the algebraical sum of the components of all the forces, resolved along any three directions, at right angles to each other, is zero.

$$\text{IV.} \quad \Sigma\,(Z \,.\, y - Y\, z) = 0 \text{ with regard to the axis of } x_0.$$
$$\text{V.} \quad \Sigma\,(X \,.\, z - Z\, x) = 0 \text{ with regard to the axis of } y_0.$$
$$\text{VI.} \quad \Sigma\,(Y \,.\, x - X\, y) = 0 \text{ with regard to the axis of } z_0.$$

That is to say, the algebraical sum of the statical moments of all the forces, about any three axes, at right angles to each other, is zero.

In all the following considerations, let the body of the ship be placed in the system of co-ordinates, as is shown in Plate XLV., so that the axis of co-ordinates y_0 is in the middle plane of the ship parallel to the water-line, in this case coinciding with the line of the keel, and the axis of co-ordinates z_0 with a vertical through the line of the keel. We see that we may, in the problem under consideration, neglect conditions I. and II., which express the liability to movement in the plane of flotation, and condition VI., which expresses the possibility of turning around the axis of z, that is to say, the steering capacity of the ship. But if forces exist, due to the resulting motions, in consequence of conditions I., II., and VI. not being fulfilled, we must consider the influence of these on the conditions III., IV., and V.

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For the problem of stability there remain then the three simultaneous conditions—

$$(a) \qquad \Sigma(Z) = 0$$
$$(b) \quad \Sigma(Z \,.\, y - Y z) = 0$$
$$(c) \quad \Sigma(X \,.\, z - Z x) = 0$$

That is to say: (*a*) *The algebraical sum of the components of all the forces applied to the ship's body, at right angles to the plane of flotation* $= 0$; (*b*) *and* (*c*) *the algebraical sum of the statical moments of all the forces about the axis of* x *and about the axis of* $y = 0$.

All the forces acting on a ship's body may be divided into three categories:—

(1) The forces of buoyancy, dependent on the weight of the displaced water, and acting through the centre of gravity of the same.

(2) The forces of gravity, due to the weight of the ship, or of its parts, and acting through the separate centres of gravity.

(3) Other forces, such as the inertia of the ship and the water, the pressure of wind, &c.; in short, all forces not included under (1) and (2).

The calculations here brought forward can, in general, only be carried out for the forces comprised under (1) and (2), but the method of solving for the forces under (3) will be given as the immediate result of the treatment of the whole question.

Before describing the three simultaneous conditions of equilibrium (*a*), (*b*), and (*c*), let us treat the problem with the limitation that only (*a*) and (*b*), or (*a*) and (*c*), are to be fulfilled, while the third condition is to be taken as forcibly fulfilled, as if the corresponding axis were held in place.

The conditions of stability have always hitherto been treated in this manner. The preliminary consideration of this simplified method of thought will prepare the mind for the following general solution.

Let us take the vessel as being inclined into a position making the angle α (Fig. 2, Plate XLVI.) relatively to the initial position, and also let the inclination take place round the axis of y_0. The result will be the displacement of a mass of water of weight G_α. This position will be brought about by the action of a series of separate weights g, the co-ordinates of the centres of gravity of which, relatively to the axes of z_0 and x_0, are x and s.

For the position of equilibrium we have—

$$(a) \qquad \Sigma(Z) = 0, \text{ whence } G_\alpha = \Sigma g;$$
$$(b) \quad \Sigma(X z - Z x) = 0,$$

or, under the sole action of gravity—

$$(b) \quad \Sigma(Z x) = 0;$$

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whence

$$G_a \cdot a_a = \Sigma g\,(p \cdot \cos a + s \cdot \sin a).$$

If the inclination takes place at an angle β about the axis of x_0, instead of at the angle of a about the axis of y_0, we shall have—

$$(a) \qquad G_a = \Sigma g$$
$$(c) \quad G_a \cdot a_a = g\,(r \cdot \cos a + s \cdot \sin a)$$

where r is the distance of the centre of gravity of the weights from the axis of z_0.

The equations (a) and (b), respectively (a) and (c), constitute, under the given limitations to the liability to motion, *the fundamental equations of the problem of stability*.

Let us now attack the problem in its general state; that is to say, let us suppose a simultaneous movement of the longitudinal axis and of the transverse axis—which corresponds to what goes on in nature; in this case also the three above-mentioned simultaneous conditions of equilibrium must be applied—

$$(a) \qquad \Sigma\,(Z) = 0.$$
$$(b) \quad \Sigma\,(Z \cdot y - Y z) = 0, \text{ or, for the weights alone } \Sigma\,(Z \cdot y) = 0.$$
$$(c) \quad \Sigma\,(X z - Z x) = 0, \text{ respectively } \Sigma\,(Z \cdot x) = 0.$$

Let the vessel, through the action of several weights g, be brought to a new position (a, β) (Fig. 3, Plate XLVI.).

Let the co-ordinates of one of the weights be p, r, s, where

p is the distance from the plane of $y_0\ z_0$
r ,, ,, ,, ,, $x_0\ z_0$
s ,, ,, ,, ,, $x_0\ y_0$

Let a denote the angle of the inclination about the longitudinal axis, and β the corresponding angle about the transverse axis.

a and β then only characterise the final positions of the initial system of co-ordinates x_0, y_0, z_0 relatively to the end system of co-ordinates x, y, z, if the axes about which each further movement of the system of co-ordinates takes place, and if, also, the order of the movement (viz., first to a, then to β, or *vice versâ*) are simultaneously designated.

For example, the final position of the points will be different, according as we turn the system of co-ordinates, first by the angle β about the axis of x_0, and then by the angle a about the axis of y_0; or, as we turn the co-ordinates first by a about the axis y_0, and then by β about the axis of x_0; or, as we, in both cases, make the second turning about the axis y or x respectively.

We must, therefore, also take care, when making a numerical calculation, that, for the determination of buoyancy, and its moments, for the position a, β, the same axes,

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about which turning takes place, are made use of as when the forces of the weights are introduced.

To make the determination of $G_{\alpha\beta}$ and $G_{\alpha\beta} \cdot a_{\alpha\beta}$ as practical as possible was the reason for taking the motions, in this case, in such a way that the ship is first inclined about the axis of x_0 to the angle $\beta = \beta_1$, and is afterwards inclined about the axis of y to the angle $\alpha = \alpha_1$.

Let us follow the individual movements till we obtain the length of the lever arms at the end of which the forces due to the weights act.

(a) The ship will be inclined from the upright position, about the axis of x_0, as far as the angle β. Then the length of the lever arm of the forces due to the weights changes to—

$$r \cos \beta + s \cdot \sin \beta,$$

where β is to be taken as positive for a movement of the axis of y towards the positive axis of z_0, in this case for an immersion of the after body of the ship, and is to be taken as negative for a movement of the axis of y towards the negative axis of z_0.

The distance of the point of application from the axis of y changes to—

$$s \cos \beta - r \sin \beta.$$

(b) If the ship is inclined from this position to the angle α about the now fixed axis of y, the length of the lever arm at which the force acts, in relation to the axis of z, does not change:

$$= r \cdot \cos \beta + s \cdot \sin \beta.$$

In relation to the axis of y it changes to—

$$(s \cdot \cos \beta - r \cdot \sin \beta) \sin \alpha + p \cdot \cos \alpha.$$

If, now, the buoyancy and its moments, likewise about the same axes, for any position (α, β) are known, we obtain—

The General Equations of the Problem of Stability.

(a) $G_{\alpha\beta} = \Sigma g$.

(b) $G_{\alpha\beta} \cdot a_{\alpha\beta}$ (in relation to the axis of x) $= \Sigma g (r \cdot \cos \beta + s \cdot \sin \beta)$.

(c) $G_{\alpha\beta} \cdot a_{\alpha\beta}$ (in relation to the axis of y) $= \Sigma g [(s \cdot \cos \beta - r \cdot \sin \beta) \cdot \sin \alpha + p \cdot \cos \alpha]$.

After this investigation of the relations between the forces due to the weights and to buoyancy, the way of dealing with the other forces is easily recognised.

(1) We must substitute the components of the forces at right angles to the plane of the water in condition (a), for the separate angles α and β.

(2) The moments of the forces in relation to the axes of x and y respectively, in conditions (b) and (c), for the separate angles α and β.

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After we have thus constituted the fundamental equations for the equilibrium of a vessel, the problems to be solved can be immediately obtained from them. They are as follow :—

(1) To calculate numerically the forces of buoyancy and its moments.

(2) To establish a connection between conditions (*a*) and (*b*) and (*c*).

(3) To introduce the moments of the external forces into the conditions of equilibrium.

(4) The general demand that the results must be clear, and, above everything, so set forth as to be suitable for practical use.

I will deal with the consideration of the first question as shortly as possible, and will only propound a short arrangement of the possible methods of calculation for the practically important case that the body of the ship heels about a horizontal axis.

We distinguish here between two methods of calculation : (1) The method of wedges (see Fig. 4, Plate XLVI.). (2) The method of integration (see Fig. 5, Plate XLVI.).

Let G_0 represent the weight of fluid displaced by a floating body in its initial position, and F_0 the centre of gravity of this weight; G_α the weight of the displaced fluid in any given position (α) of the vessel relatively to its initial position, and F_α the centre of gravity of this weight; g_α^e the wedge g of emersion, for angle α, for the change of position from G_0 to G_α; g_α^i the corresponding wedge g of immersion for angle α; a, b, c lengths of lever arms, γ the specific weight of the water.

(1) The method of wedges (Fig. 4).

$$(a) \quad G_\alpha = G_0 + g_\alpha^i - g_\alpha^e.$$

$$(b) \quad G_\alpha \cdot a_\alpha = G_0 \cdot a_0 + g_\alpha^i \cdot c + g_\alpha^e \cdot b.$$

(2) The method of integration.

$$(a) \quad G_\alpha = \int d\,G.$$

$$(b) \quad G_\alpha \cdot a_\alpha = \int d\,G \cdot a.$$

Any volume may be expressed thus : $\int\int\int dx \cdot dy \cdot dz$.

If, now, we do not use a method for measuring directly the capacity, such as the small models sometimes employed to determine the volume and the moments, we absolutely require co-ordinates for measuring the area, in order to effect this purpose.

The practical carrying out of both methods is now only conditioned by the choice of these co-ordinates for measuring area. These may be either :—

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(*a*) Polar;

(*b*) Perpendicular to the original water line;

(*c*) Perpendicular to the water-line at any given time;

(*d*) Parallel to the original water-line;

(*e*) Parallel to the water-line at any given time.

We thus obtain, apart from making direct use of the volume, $2 \times 5 = 10$ different methods for determining the forces of buoyancy and its moments. Each of these processes of calculation further permits of an endless number of subdivisions, according as we make use of calculation, the integrator, graphical methods, a mixture of any of these processes, or vary the order in which the integrations are carried out.

The processes of calculation, nowadays available, are far from exhausting the above-mentioned possibilities; they are, however, numerous enough to satisfy practical requirements, and further work in this direction will extend, but not advance, the problem of stability.

It has still only to be remarked that the method of wedges cannot always be used, but the process of integration must always serve, instead, for the calculation of the buoyancy and the moments for any position of the vessel (α, β).

The following questions are more important and more interesting than the preceding:—

First, How is a connection between equation (*a*) and (*b*) and (*c*) to be attained?

It is impossible to explain here the solutions which have hitherto been given. This has been already done by the author in a work called "Stabilitätsproblem des Schiffbaues" ("The Problem of Stability in Naval Architecture"),* in which the foundations here given have been elaborated.

There are only two methods:—

Mr. Barnes and Sir William White substitute equation (*a*) in equations (*b*) or (*c*) directly; all other methods carry (*a*) by interpolation into (*b*) or (*c*) respectively.

As to the third point, the connection between the exterior forces and the buoyancy; hitherto the law was only known for the simple case that the force due to the weights acts in the plane of symmetry of the ship, viz.,

$$G_a \cdot a_a = G \cdot s \cdot \sin a.$$

I should prefer, in order to make known the present state of the problem of stability, to repeat the words of the highly honoured Sir Edward Reed, which he made

* Berlin: published by George Siemens.

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use of in his interesting paper on "The mathematical Theory of Naval Architecture" given to last year's Congress of Naval Architects and Marine Engineers, viz.:—

"In order to acquire a just conception of the progress made since (1860), we must carefully bear in mind that we have had no new elements and no new principles to deal with since then; all that could be done was to present the old materials in new aspects or in new combinations, having due regard to the improvement of the practical calculations, for in every ship or shiplike floating body, detailed calculations or equivalent mechanical experiments must be made to suit the particular case presented, if they are to be more than approximate. It is only in theoretical cases, such as those of bodies of symmetrical form, or in mere approximations, that exact calculations can be dispensed with."

I now turn to the application, which I have given, of the determining quantities, to the connection of (*a*) with (*b*) and (*c*), and to the combining of the moments of the external forces with the moments of buoyancy.

In the first instance the problem will be solved on the limited assumption that one of the conditions of equilibrium, (*b*) or (*c*), is forcibly fulfilled.

Then we find, for any given position of the vessel in the water, a connection between the four following quantities:—The buoyancy G; the moment of the buoyancy M about any given axes; the depth of immersion t; and the angle of heel α; and, moreover, the connection is of such a sort that, when two of these quantities are known, the other two are generally clearly determined.

We have then, in order to characterise any given position, only two quantities at our free disposition, *e.g.*, α and t, t and G, t and M, &c.

Let us now take one of these quantities as being known, then there remains only one simple relation between the three other quantities.

Let us mark off, for example, in a system of rectangular co-ordinates, corresponding to $\alpha = \alpha_1 =$ constant, on one axis, various depths of immersion t, and, perpendicular to the same, for every value of t the corresponding buoyancy and its moments (see Fig. 6, Plate XLVI.), we obtain from the resulting curves of G and M the value of G and M corresponding to every value of t for the special case $\alpha = \alpha_1$.

Let us now imagine these separate systems of co-ordinates for $\alpha = \alpha_1, \alpha_2, \alpha_3 \ldots$ combined in a system of co-ordinates of space (rectangular or polar) in such a way that t and α lie in a horizontal plane of co-ordinates; thus we obtain from the combination of the curves M and G (α = constant) surfaces of M and G which possess the peculiarity that, for every point of the one surface the corresponding point of the other surface lies in the intersection of the perpendicular drawn from this point to the original horizontal plane.

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Instead of starting from a and t, we could equally well have chosen two other quantities. For instance, we could have taken t as constant and a variable, or we could have taken a and G together, or M and G together.

The particular way which we choose depends upon practical considerations. If we follow the natural method of calculation, we start from a and t, but take the M in the horizontal plane and form surfaces of G and t.

By means of the explanation just given the substitution of (a) in (b) or (c) and the finding of the separate values as a function of two others are reduced to problems of descriptive geometry, therefore the fundamental principles of descriptive geometry are available here. If, in making projections, the lines of intersection are long, or, if the surface foreshortens too quickly, we must turn it about an angle of 90°, or any other angle (see Plate XXXVII.); we raise the surface in order to obtain an underneath view, and lower it to obtain a view from above, and thus we can always obtain any desired degree of accuracy in the points of intersection.*

We now draw the diagram of surfaces in such a way that we place the side projection of the above described solid surfaces in the plane of the picture.

This gives the following construction :—

We set off in a system of polar co-ordinates (any other system can also be made use of) on the radii vectores a_1, a_2, &c., the moments pertaining to $a = a_1$, t being variable. We then set off the values of G and t, corresponding to each value $a = a_1$, $t = t_1$, $t = t_2$, in a second and third system of rectangular co-ordinates derived from the first one. This we repeat for each value of the angle a, so far as it is intended to examine the movement of the vessel, and then join the points G and t into curves $a =$ constant.

If now, the moments, or immersions, for G = constant are to be found out, we draw in the G diagram the line G = constant. By projecting the points of intersection of this line with the separate curves G, for a = constant on to the radii of the polar diagram, we obtain the moments, and by projecting them on to the corresponding curves t we obtain the immersions t.

The other diagrams are constructed in the same manner as Plate XXXVII., but in these, instead of the moments, we make use also of the moments divided by sin a, and, instead of polar, we make use also of rectangular co-ordinates.

The substitution of equation (a) in (b) and (c) is effected in all the Plates in the same way as in Plate XXXVII.

The substitution of (a) in (b) and (c) is always possible, even in the case where G is given as a function of one of the other quantities.

* The author here placed before the meeting an actual surface of this description.

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When we have recognised the simplicity of the substitution of (a) in (b) and (c), we have still to answer the question, *How do the external forces enter into the equations of the moments of buoyancy?*

The equation of the forces due to the weights is as follows:—

$$g\,(s\,.\,\sin a + p\,.\,\cos a);$$

$s\,.\,\sin a + p\,.\,\cos a$ represents the polar equation of the circle, the pole of which lies in the circumference, and the rectangular co-ordinates of the centre of which are $\frac{s}{2}$ in relation to the radius vector of 0°, and $\frac{p}{2}$ in relation to the radius vector of 90°.

If then the point of application (p, s) and the value (g) of the force due to the weights are given (Plate XXXVII.), describe a circle in the polar diagram about $\frac{p\,.\,g}{2}$ and $\frac{s\,.\,g}{2}$ passing through O. The difference of the radii between the circumference of the circle and the previously obtained curve of the moments of the forces of buoyancy gives the reserve moments, the intersection of the circle with the curve gives the angle of the position of equilibrium.

It must only be remarked that the size of these differences, even in the case of the smallest angles, can be obtained absolutely distinctly, viz.: the segment of the moment of buoyancy by projection from the diagram of the weights, or from the diagram of immersions; the segment of the circumference of the circle by means of the perpendicular let fall from the point diametrically opposite to O upon the radius vector. The position of equilibrium can also be obtained, to any degree of accuracy, by drawing the curve of reserve moments in the well-known manner, in a new system, as $f\,(a)$.

If the forces are not due to gravity, the curve will generally not be a circle, but everything else will remain the same.

In spite of the simplicity of this solution, a modification of the method, as developed above, might be recommended in trim problems, in which we generally require an immediate and accurate determination of the angle of equilibrium.

Let us divide the equation—

$$G\,.\,a = \Sigma\, g\,(p\cos a + s\,.\,\sin a)$$

by $\sin a$; we then obtain—

$$\frac{G\,.\,a}{\sin a} = \Sigma\, g\,(p\,.\cot a + s).$$

Now it is just for small angles that $\frac{G\,.\,a}{\sin a}$ has a large value, while $\cot a$ approximates to infinity, and thus presents, at small angles, the best imaginable points of intersection.

This method appears to possess one disadvantage: the value of the moment $\frac{G\,.\,a}{\sin a}$, when $a = 0$ and $a = 0$, equals $\frac{0}{0}$, that is to say, an indeterminate form.

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For the investigation of this expression we must revert to the method of wedges (See Fig. 4, Plate XLVI.)

Let us take the origin of co-ordinates in this method as being in the centre of buoyancy in the initial position F_0, thus we obtain the expression, following the rules for the determination of $\frac{0}{0}$—

$$\frac{G_a \cdot a_a}{\sin a} \text{ (when } a = 0, \text{ and } a_a = 0) = \frac{2}{3}\gamma \int r^3 d\,y$$

$= \gamma \times$ moment of inertia of the original water-line.

The value of $\frac{G_a \cdot a_a}{\sin a}$ when $a = 0$ is therefore a finite quantity for the special case when the origin of co-ordinates is situated in the centre of gravity of the displacement, or, in the perpendicular through this centre of gravity. As we have placed the origin of co-ordinates in the line of the keel, in the perpendicular through the centre of buoyancy, we must add the value of $G \cdot O F_0$ to the moment of inertia of the water-line, $O F_0$ being the distance between the centre and the line of keel.

In practice, however, this calculation is quite unnecessary; for, if we approximate sufficiently in the calculation to the zero position (*e.g.*, up to 10°) the value is determined accurately enough by the direction of the curve. (See Plate XXXIX.)

The combining of the moments of external forces with the conditions of the general problem does not yield a single direct solution. For, in addition to the four quantities a, t, M, and G, we have to deal with the angle β. The representation by means of one solid surface is therefore not available. We can, nevertheless, construct the well-known solid surface for each separate position β, in the same way as we have already done for the case when $\beta = 0$. It is possible, by means of these surfaces, constructed for various values of the angle β, to find a series of relations between a and β; the simultaneous existence of (*b*) and (*c*) enables us then to obtain single solutions of the value of a and β. The description of the example selected will make what has been said perfectly clear.

Before, however, entering into the description of the problems of stability, we may still be permitted a few words on the limiting value of the expression—

$$\frac{a_a}{\sin a} = \frac{0}{0}, \text{ when } a = 0.$$

Let us represent—

$$\frac{a_a}{\sin a}, \text{ when } a = 0,$$

as being dependent on a; then we recognise immediately that, for every finite value of a, the moment $= \infty$; and, indeed, the curve is so constituted that its branches on both sides of the vertical, drawn through the centre of gravity of the displacement, lie

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in infinity; the cusp alone, for the special case $a = 0$, will be an isolated point at the distance—

$$\frac{2}{3}\gamma \int_{G} r^3 \, dy$$

from the centre of gravity of the displacement in the initial position.

This expression represents also the radius of curvature of the curve of the centres of gravity of the displacement for any given angle of inclination α (also for $\alpha = 0$).

Bouguer was the first to introduce this radius of curvature. *The accidental coincidence of this centre with the isolated point obtained above* caused him to introduce the length M F_0 of the radius of curvature (see Fig. 7, Plate XLVI.) in the initial position as a measure of the stability. Since that time this length has remained in use as a measure of the initial stability, and has the merit, for many long decades, of having rendered every investigation of stability, based upon a correct manner of regarding the forces, impossible.

It is the merit of men like Sir Edward Reed, Sir W. White and the late William John, which cannot be sufficiently praised, that they, at last, came back from the far-off region of infinity to reality, and constructed the first curve of lever arms; it is, however, in my opinion, the invaluable merit of the late Professor Jenkins to have built the bridge from infinity to finite regions, and to have shown us the proper signification of the mathematical expressions hitherto used as linear quantities in the construction of the curve, and which are solely useful for appreciating stability.

In the year 1889 the reading of this most important paper took place before this Institution, viz.: "On the Connections between the Curve of Stability and the Metacentric Curve."

Perhaps I may be permitted to remind you shortly of the context (see Fig. 7, Plate XLVI.)—

$$d\,a = \mathrm{M\,G} \cdot d\,\alpha;$$

$$\mathrm{M\,G} = \frac{d\,a}{d\,\alpha} = tan\ \varepsilon,$$

where ε represents the angle of direction of a curve, $a = f(\alpha)$, and consequently the angle of direction of the curve of lever arms a.

The quantity M F_0, when we regard it as the limiting case of $\frac{a_\alpha}{\sin \alpha}$ for $\alpha = 0$, $a_0 = 0$ has a direct connection with the stability problem; but the curve of centres of curvature of the centres of gravity of the displacement has no relation to the same, and neither has its initial value M F_0 for $\alpha = 0$.

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How great is the danger that our conceptions may get mixed up. The proofs of this are furnished by the history of this question for a century.

Is it, however, absolutely necessary that we should always continue to make use of this linear quantity? Professor Jenkins has given us the amount of the initial stability, which is so much simpler and so much more in harmony with the scope of our understanding.

It is only necessary, in order to keep the size of the angle absolute, to regulate the units of the angle, and who could be better called upon to settle this question than you who constitute the first court of judgment for all the shipbuilders of the earth?

The greatest values of G M, which we have to deal with, amount to 2 to 4 metres; let us choose as the radius of the circle necessary for determining the amount of the angle, $r = 1$ metre $= 3$ ft. $3\frac{3}{8}$ in. We then obtain, for example, for the metacentric height of 2 metres, $\alpha = tg\ 2 = 63^\circ\ 20'$, to be taken directly from our curve of lever arms.

The curves of the reserve moments on Plate XXXVII. are also represented by this unit. *If, in the future, we always choose the same unit when drawing curves of stability, it will be possible to compare the stability curves when always drawn in the same way, and thus to take in, not only the initial angle of direction, but also the character of the whole curve, and the course of its rising and falling for individual forms and types of ships, and to carry them about with us as a concrete image.*

Fig. 7A, Plate XLVI., will show how it comes about that ships having precisely similar circumstances of stability have, nevertheless, such different metacentric heights, that is to say, how the stability curves spring at totally different angles from the zero position, and the separate curves, nevertheless, soon afterwards unite into a single one.

Let us now pass to the practical use of the fundamental equations in the separate problems of stability.

The calculations for the accompanying sheet of diagrams were performed by means of the integrator. In order to further the explanation of the general problem of stability, let us recapitulate shortly the method used for the calculation.

The vessel was placed on the line of the keel in the manner shown in Plate XLV., and normal transverse planes set up perpendicularly to the surface of the water through the points of division (1-39) for $\alpha = 0^\circ$; $\beta = +5^\circ$; $\beta = 0^\circ$; $\beta = -5^\circ$. These transverse planes are marked out separately for the fore and after bodies of the ship. Figs. 8 and 9 (Plate XLVII.) show two sets of the drawings of these transverse sections.

Each set of these transverse sections is then placed under tracing paper covered over with the parallel lines O, *a*, *b*, *c*, &c., and the point O is fixed on the line of

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keel. Then the transverse sectional areas are obtained by the well-known method, and also the moments of the same in relation to the axis O O at angular intervals of 10° and immersions starting from zero and proceeding to complete immersion.

These transverse sectional areas and moments are then combined in the manner shown on Fig. 10 (Plate XLVII.) for a given angle α and β.

We then obtain the total displacement, when $\beta = 0$, for immersion $t = t_1$ and $\alpha = \alpha_1$, after drawing out the corresponding transverse areas in the longitudinal plane—displacement scale—(Plate XLV.), by integrating this displacement scale, and after drawing out the corresponding moments in the longitudinal plane, we obtain the moment of the displacement about the axis of y_0 by integrating the curve of the moments; and we obtain the moment of the displacement about the axis of x as the moment of the displacement scale about the axis of O z_0. Areas and moments are only to be calculated up to 90°; the values for greater inclinations are given directly by the relations (see Fig. 11, Plate XLVII.)—

$$(a) \quad G_{(180-\alpha)} = G_v - G_\alpha$$

$$(b) \quad G_{(180-\alpha)}\, a_{(180-\alpha)} = G_v \,.\, a \;\; - G_\alpha \; a_\alpha$$

If the position of the vessel is turned about an angle $\beta = +5°$, or $\beta = -5°$, we must consider that the plane of the water intersects the separate transverse sections at different heights. Consequently, the displacement scale and the scale of the moments to be represented in the longitudinal plane are seen to be, not straight lines, but curves, in the plane of the transverse sectional areas and moments (see Fig. 10, Plate XLVII.).

The difference of height between the feet of two transverse sections, measured at right angles to the surface of the water, amounts to—

$$b \,.\, \sin\beta \,.\, \cos\alpha,$$

where b is the distance between the two transverse sections, measured along the line of the keel.

Let us then cover the drawing represented in Fig. 10 with a network of parallel lines drawn apart at the distances $b \sin\beta \,.\, \cos\alpha$, the zero line going through the foot of transverse section No. 39; we can then find the displacement scale and the scale of the moments to be drawn in longitudinal plane by connecting the corresponding points of intersection.

The displacement of the vessel in any position β, α, and t is then the area of the displacement scale for β, α, and t; the moment of the displacement about the axis of x is the moment of the displacement scale about the line O z. The moment of the displacement about the axis of y is then represented as

Σ (of the moments of [the single transverse sectional areas about the foot of the frame] $d\,y$) + Σ (of the moments of [the transverse sectional areas $a \,.\, \sin\beta$] $.\, d\,y$);

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Or, it equals the integral of the scale of moments drawn out in the longitudinal plane plus the moment of the displacement scale about the line O z multiplied by sin β.

This last value has been already obtained.

The same operations are to be repeated for all the angles β, all the angles α, and all the immersions.

The limits here observed are—

$\beta = + 5°$; $\beta = - 5°$
$\alpha = 0°$ up to $40°$
t = from zero up to complete immersion.

The Plates XXXVII. to XLIV. correspond with these calculations. Sometimes rectangular co-ordinates are chosen in the diagrams of moments, and sometimes polar co-ordinates; also sometimes the moments, and at other times the $\frac{\text{moments}}{\sin \alpha}$ are made use of, just as it might be suggested by practical considerations.

Plate XXXVII. Diagram surfaces of the displacements, of the moments of the displacements, and of the immersions for $\beta = 0$; $\alpha = 0°$ up to 180°, the moments being taken about the axis y_0.

Plate XXXVIII. Ditto, the moments being taken above the axis of x.

Plate XXXIX. Similar to Plate XXXVII., but the moments divided by sin α between the limits 0° and 90.

Plate XL. $\beta = + 5°$; $\alpha = 0°$ up to 40°. The moments are divided by sin α and taken about the axis of y.

Plate XLI. Ditto for $\beta = - 5°$.

Plate XLII. $\beta = + 5°$; $\alpha = 0°$ up to 40°. Moments taken about the axis of x.

Plate XLIII. Ditto for $\beta = - 5°$.

Plate XLIV. Moments of the buoyancy, &c., for $\alpha = 0°$; $\beta = + 10°$ to $- 10°$. Moments are taken about the axis of x_0.

Plates XXXVIII. to XLIII. deal with the problems of general stability. Plates XXXVIII. and XLIV. constitute the diagrams which alone are necessary for ordinary investigations. *It must be particularly pointed out that, in the complete calculation of these two latter plates, not a single value has to be obtained more than in the calculations hitherto generally used; but all the quantities which enter into the calculations are really made use of in investigating the stability.*

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Let us now approach the solution of stability problems; but with the limitation always observed at first, viz., that one axis is artificially held fast.

Problem 1.—Plates XXXVII. and XXXIX.

Let the vessel in question have a displacement G = 1,800 tons. The position of the centre of gravity is given in the plane of symmetry. The qualities of stability are to be investigated.

Solution.—The line G = 1,800 tons is to be drawn in the diagram of the displacement, and the points of intersection projected on to the corresponding lines of the moments and immersions.

Since $p = 0$, the centre of the circle of weights lies on the radius of 90° at a distance $\frac{G \cdot s}{2}$ in Plate I. From this centre describe a circle through O; we then obtain the reserve moments directly, by taking the distances on the radius vector between the intersections of the curve of the moments of the displacement and the periphery of the circle. In Plate XXXIX. describe a circle about the point O with $G \cdot s$ as radius, and then only multiply the reserve moments by $\sin \alpha$; the values can be taken directly from the figure.

Problem 1A.—The reverse of the above. The position of the centre of gravity is to be so fixed that it lies in the plane of symmetry of the vessel, and the stability of the vessel at 70° = 0. G = 1,800 tons.

The solution can be derived directly from the foregoing.

Problem 2.—The centre of gravity of the system lies outside the plane of symmetry, in the points p and s. The displacement of the vessel is 2,800 tons. The position of equilibrium of the vessel is to be found out, and also the qualities of stability.

Solution.—(See Plate XXXVII.)

The centre of the weight circle no longer lies in the radius of 90°, but is removed from it by the distance $\frac{Gp}{2}$. The circle is described from this point through O, and gives directly the reserve moments.

In Plate XXXIX. the quantity $G \cdot p \cdot \cot \alpha$ is to be added to the radii vectores of the circle described about O with radius $G s$. Otherwise as in Problem 1.

Curve a represents a position of the centre of gravity of the system in the axis z_0.

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Curve b a similar position removed to a distance p from the axis of z_0 on the side opposite to that of the natural movement showing the influence of shifting ballast in yachts.

Curve c a similar position when p is removed to the same side as that of the natural movement.

In the case of this last movement equilibrium will occur in the point of intersection of the circle with the curve of moments, that is, to say 20°. The depths of immersion corresponding to each separate position are to be taken directly from the diagram of immersions.

Problem 2A.—The reverse of the above.

The position of equilibrium of a vessel of 2,800 tons displacement corresponds with an inclination α. Where must the centre of gravity lie ?

We see that the problem is indeterminate, since p and s can both vary. Insight into the stability curves to be directly observed (we only require to shift the points of the compasses and to remark that the circle of the weights must always pass through O), or other practical relations, the limiting position where the stability vanishes, &c., will, without difficulty, lead to a solution.

Problem 2B.—The reverse of the above.

A vessel may, at the utmost, be inclined over to an angle α, at which the edge of the deck may not be submerged ; for example, take the case of a floating crane. Where must be the centre of gravity of the same, and what is the displacement and the righting moment at this inclination ?

We mark on the body plan the limit which is considered permissible ; we thus obtain directly α and t. Now draw the curves for α in the three diagrams ; we then obtain from the immersion diagram the point which corresponds with the immersion (t, α), and by projection on the other two diagrams we get the displacement and the moment of buoyancy which is effective in this position. Thus the problem is reduced to 2 a.

Problem 3.—(See Fig. 12, Plate XLVII.)

A portion of the weight in a vessel, which is in the upright position, is transferred from the position p_1 s_1 to p_2 s_2 ; what is the new position of equilibrium, and what are the new circumstances of stability ?

The conditions of equilibrium are as before—

$$(a) \quad G_\alpha = G - g + g$$

$$(b) \quad G_\alpha a_\alpha = G \,.\, s \,.\, \sin\alpha + G \,.\, p \,.\, \cos\alpha + g\,(s_2 - s_1) \sin\alpha + g\,(p_2 - p_1) \cos\alpha.$$

Therefore the co-ordinates of the centre of the circle of the weights change from—

$$\frac{G \,.\, s}{2} \text{ to } \frac{G \,.\, s}{2} + \frac{g\,(s_2 - s_1)}{2}$$

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and from—

$$\frac{G \cdot p}{2} \text{ to } \frac{G \cdot p}{2} + \frac{g(p_2 - p_1)}{2}$$

The signs of p_1 and p_2 have to be considered according to their position in system of co-ordinates.

Problem 3A.—The reverse of the above. A vessel whose centre of gravity is in the position p and s is inclined at an angle α. How must a weight (p_1, s_1) be shifted in order that a second position of equilibrium α_1 may be obtained?

Here, also, we must obtain a connection between p and s by considering practical conditions and the existing relations of stability, by means of trial with the point of the compasses.

Problem 3B.—Let a vessel, *e.g.*, a floating crane, attain a certain position when the crane with the weight g is swung in. The centre of gravity in this position is situated at p and s. How far may the weight be swung out without submerging the edge of the deck?

We have in G = constant the law for the movement of the hull in the water, and we find the limiting angle α of the heel by drawing in the plane of flotation on the body plan for different inclinations. As the curve of moments of displacement is known, we obtain a second point in the circle of weights by the intersection of this curve with the radius at the angle α. If, when the weight is swung out, s_1 remains constant, then p_2, the quantity sought for, is determined.

Problem 4.—A new weight g is put on board a vessel in the position p_1, s_1. What position will the vessel take, and what are the conditions of stability and the immersion? We have:—

(*a*) $G_\alpha = G + g$.

(*b*) $G_\alpha \cdot a_\alpha = G \cdot s \cdot \sin \alpha + G \cdot p \cdot \cos \alpha + g \cdot s_1 \sin \alpha + g p_1 \cos \alpha$.

We construct the curve $(G + g)$ in the diagram of the moments and immersions, and proceed as before in Problem 3.

Problem 4 is the most important one in stability questions, as it is the foundation in the following calculations:—

(1) Of the effects of leaks and bulkheads.

(2) Of the action of sails.

(3) Of the effect of going aground.

It is impossible for me to go more into detail with these processes. They all constitute applications of Problem 4.

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Plate XLIV. contains the diagram which is to be employed in the calculations for leakage and spacing bulkheads; the problem illustrated by it is as follows :—

The angle $\beta = 3^\circ\ 10'$ and $t = 2\ m$; what is the displacement and the moment of the displacement?

The action of sails is only of interest in so far as the wind pressure exercises not only a heeling effect, but also a downward pressure. It enters, therefore, both into conditions (*a*) and (*b*) as a function of the angle of heel.

I can only refer to the work which I have mentioned above, in which the three problems are treated in detail.

I now quickly revert to the problem of stability in its complete generality, *i.e.*, we permit a simultaneous inclination of the longitudinal axis equal to β, with that of the transverse axis equal to α, the law of which inclination was explained at the beginning. Let t be the perpendicular distance from the origin of co-ordinates to the plane of flotation at any time.

Let the following problem be given :—The centre of gravity of the vessel is in the following position—

$$p = 0{\cdot}6\ m; \qquad r = 45{\cdot}0\ m; \qquad s = 3{\cdot}6\ m,$$

the displacement amounts to 2,200 tons. What position does the ship assume in the water? The position is denoted by α, β, and t.

We first introduce the condition G = 2,200 tons into the separate diagrams in the well-known manner, and thus obtain the moments of buoyancy and the immersions corresponding to this displacement.

The weight of the body of the ship with co-ordinates (p, r, s) now enters into the diagram of moments with the lever arms obtained above, viz.—

In Plates XXXIX., XL., and XLI. (moments taken about the axis of y)—

$$G\,[(s \cdot \cos\beta - r \sin\beta) \sin\alpha + p \cdot \cos\alpha].$$

In Plates XXXVIII., XLII., and XLIII. (moments taken about the axis of x)—

$$G\,(r \cdot \cos\beta + s \cdot \sin\beta).$$

We recognise that a condition of equilibrium does not exist in Plates XXXVIII., XLII., and XLIII.; but we see that there must be a condition of equilibrium between the positions $\beta = +\ 0^\circ$ and $\beta = +\ 5^\circ$, because the moments of the weights are in the one position greater, and in the other less, than the moments of buoyancy.

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Let us, therefore, set off, in a system of rectangular co-ordinates (see Plate XLIII.), the angles β as abscissæ, and the moments of the buoyancy and of the weights as ordinates for each separate angle α; we thus obtain in the points of intersection of the corresponding lines a relation of the possible positions of equilibrium between α and β; the moments are taken about the axis of x.

In Plates XXXIX., XL., and XLI. we obtain directly connections between α and β, the moments being taken about the axis of y.

Let us now introduce the relationships obtained in regard to the axes of x and y, into a rectangular system of co-ordinates (Plate XLI.) having axes of β and α; we then find, in the points of intersection of the two resulting curves, the angles α and β, which conform to the required conditions.

We now only require to determine the value of t.

Let us introduce the values of $t = f(\alpha)$ from the diagrams of immersion in Plates XXXVIII., XLII., and XLIII. into our first system of rectangular co-ordinates, Plate XLIII.; then we find, directly, t corresponding to the conditions of equilibrium. Let us transfer these values into the last system of co-ordinates (Plate XLI.); we then find (by transferring the points α, β, which we have obtained), the value of t corresponding to the position of equilibrium.

If we were to work from the values of t obtained in Plates XXXVIII., XLII., and XLIII., the same value t must be obtained; this constitutes a test of the correctness of the result, which is always to be desired.

We could now ask, being guided by the curve of reserve moments of the limited problem, "How do the moments come out if the vessel is further inclined?" The question, however, in this form cannot be answered simply; on the contrary, there are available $2 \times$ an infinite number of ways by which the vessel can change from any one position into a neighbouring one; as a matter of fact, it will follow the line of least work. The work to be performed in so doing is, in the first place, dependent on the distribution of the mass of the body of the ship; and in the second, on the resistance of the fluid to be displaced. This question cannot be included within the limits of our task.

We could certainly construct a law of the movement, as it would take place, for example, if the vessel were to leak. In any given position (p, r, s) a steadily increasing force acts, due to the weights. In such a way of putting the question, it is certainly possible to determine the path of the vessel as a series of positions of equilibrium and also the moments, in each position, as resultants of both sets of moments taken about the longitudinal and transverse axes. The problem would, however, only be another repetition of the examples already solved.

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We could also figure to ourselves the motion as being so brought about that, (analogously to Problem 3) a portion of the weights g is transferred from one position ($p_1\ r_1\ s_1$) to a second position ($p_2\ r_2\ s_2$), while, at the same time, g steadily increases. All these problems are of little value for judging of the actual motion, because they give a statical solution for a dynamical problem, and, at the best, only present quite special cases of the infinitely numerous possible motions.

I thank you, gentlemen, for the patience with which you have listened to my, necessarily, somewhat detailed and, maybe, not quite lucid explanations; and, finally, I beg you to kindly consider the following:—

Knowing, as we do, that the further use of the metacentric height, as a linear quantity in naval architecture, involves a continuous danger, might it not be advisable to use in future the initial angle of the curve of lever arms, as a measure of the initial stability, and so that the radius of the circle (the periphery of which is used as the axis of abscissæ of the stability curve) $r = 1$ metre $= 3$ ft. $3\frac{3}{8}$ in.

DISCUSSION.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Gentlemen, Professor Biles has been good enough to undertake to make a statement respecting the scope of the paper which Herr Gümbel has contributed. It would be convenient if he were now to do so.

Professor BILES then gave to the meeting a summary of the paper.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): I am sure we are all greatly indebted to Professor Biles for the trouble he has taken in giving us this clear explanation of the author's intention. We are also greatly indebted to Herr Gümbel for contributing the paper. I believe that Captain Kriloff has made a study of this subject and of this particular paper, and I will ask him if he will be good enough to open the discussion.

Captain A. KRILOFF (Associate): Sir William White and Gentlemen, I have not studied this paper so closely as its value and the skill of the author deserve, and therefore I will confine myself to a few remarks. First, I would like to see corrected the misprints in the formulæ IV., V., VI., &c., where, in the expressions of the moments the sign plus is to be replaced by minus. Secondly, I believe on page 2, under heading (3), the forces of inertia of the ship and water ought not to be mentioned. The forces of inertia interfere only when the ship is in motion, and the author is considering equilibrium, where the forces of inertia are zero. His methods would not apply to the study of the stability of a state of motion, say to the stability of a ship on waves, the study of which requires quite other considerations than are here developed. I would also suggest to the author another choice of axes of reference and of the angles α and β which define the position of the ship. This choice might be the same as in my paper, and, instead of the angles α and β of the rotation of the ship, it

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would be simpler to introduce the Eulerian angles. This would avoid the unnecessary complication of considering the order of rotations as is done in the author's paper, the Eulerian angles defining the position of a solid in a unique manner. I make this suggestion, not because such a choice of axes is made in my paper, but because, in dealing with such matter, the authority of such a genius as Euler is not to be neglected. I have only taken, out of the eighteen modes of defining the Eulerian angles, that which was the most appropriate for my special purpose, and it must be remembered that, in geometry and mechanics, a convenient choice of axes of reference implies the simplicity of the solution of the problem and of the calculations it requires. On page 223 the author would like to reject the word metacentre from the consideration of stability, and I cannot agree that the length $\rho = \frac{T}{V}$ had "rendered every investigation of stability, based upon a correct manner of regarding the forces, impossible." There existed, indeed, a very well-known misunderstanding, but how can the consideration of the above length be rejected if it defines the position of the metacentre, and M. Duhem has shown last year in the *Journal des Mathématiques Pures et Appliquées*, that the well-known condition of the stability of equilibrium of a floating body expressed in symbols as $\frac{T}{V} - a > 0$ with the usual notation, or, in words, that the centre of gravity be below the metacentre, is not only *necessary*, but also sufficient. But I must confess that the study of Duhem's paper is not an easy thing. I would also like to see the author giving more details of the calculations which he had to perform to obtain the results which he had so skilfully plotted down. These calculations, although performed by the aid of the integrator, represent an immense amount of work. My remarks must not be understood as implying in the slightest manner any doubts of the value of this paper, it is only our Russian innate pessimism which causes my fellow countrymen to search "in a cask of honey for a spoonful of tar." From the kind manner in which my own paper was here discussed, it seems that you Englishmen would, on the contrary, find a spoonful of honey in a cask of tar. I must now add that Herr Gümbel is a pupil at the Polytechnicum at Berlin, and I congratulate Professor O. Flamm on having students who make such valuable contributions to science as Herr Gümbel.

Sir Edward Reed, K.C.B., F.R.S. (Vice-President): I should be very pleased to speak on the paper if I were able; but, the truth is, I have been very unfortunately circumstanced this week, and I have not been able to read either of the papers, owing to a little accident I had, and owing also to an unfortunate fall of work on my head just as these meetings commenced. But, notwithstanding that, I should not like the author to feel, from the limited nature of the discussion upon it, that the paper has been treated with any want of respect or consideration. I am quite sure it is one of those papers which will be thoroughly studied by many members of the Institution, and thoroughly appreciated; but it is only those—and nobody will know that better than the author—who have had time to read the paper with real care and study, who will be able to do justice to it in a debate of this kind. I hope, therefore, the author will not infer from the limitation of the discussion any want of interest in the paper on the part of the Institution.

The Chairman (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Gentlemen, you will agree with what Sir Edward Reed has just said upon this subject. Before we close the discussion and ask the author to make any remarks which he may desire to make, I should like to state that, when the late Mr. William John and I were working at the calculation of the earlier curves of stability (for which some results were produced in our paper of 1871), we were not slow to note that the convention which supposed the inclinations to take place about an axis fixed longitudinally,

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but free to move vertically, was only a convention. For certain typical vessels we recognised that this matter might become of great importance. In low-ended ships, for example, when transverse inclination took place under the ordinary hypothesis, a serious tendency to change of form might be involved. We therefore followed the matter out, and determined by calculation the effect of adjustment of trim upon transverse stability. Having tested the matter in that way for certain extreme examples, we settled down to the general use of the convention as sufficient for all practical purposes. This work was done about thirty years ago. I mention it now because I want the author to understand that we quite appreciate the object he has in view, and the general mode of treatment which he has attempted. It is extremely probable in the passage on page 214, to which Captain Kriloff referred, that the author was dealing, not with the condition which he assumed in the paper, but with the conditions of actual experience. I quite agree with Captain Kriloff that, under the statical conditions with which the paper deals, *inertia* does not come in. It will be noted, however, that the author also refers to the pressure of wind and other circumstances which occur in nature, but which are not dealt with in the paper. Herr Gümbel will understand that, in accordance with the custom of the Institution, when this discussion has been printed it will be sent to him for perusal, and he will be given an opportunity of making a reply in writing to any points that have arisen. I convey to the author, on behalf of the Institution, our most sincere thanks for this very excellent paper.

Herr L. GÜMBEL: Sir William White and Gentlemen, to the objections of Professor Kriloff I reply as follows:—First, the choice of the plus sign in formulæ (IV.), (V.), and (VI.) is incorrect, and has been replaced by minus. Secondly, Professor Kriloff objects to the mentioning of the forces of inertia of the ship and of the water on p. 214 under (3). Professor Kriloff goes still further, maintaining that I was of the opinion that equilibrium took place at the point where the forces = 0; or, more correctly, where the moments of the forces of inertia = the moments of buoyancy. But nothing leads to this conclusion. I separate the forces acting on the ship generally, without respect either to the statical or dynamical effects, into three categories, and we must not forget the forces mentioned by Professor Kriloff in his own paper on p. 147 under § 2 and § 3. But, as so indulgent a critic as Professor Kriloff could object to the sense in question, it leads me to the following digression:—When is the problem of stability statical? The problem is statical: firstly, when the body is without mass, and, at the same time, secondly, the forces are not influenced by the work done in heeling the ship. Assuming this definition, the following problem will be a statical one: A wind of a given velocity acts on a sail, what is the heel of the ship? The problem remains still a statical one for the problem: The wind acts with a sudden impulse, viz., a squall. The angle of heel will in the two problems—assuming a vessel without mass, and neglecting the alteration of wind pressure by the relative velocity—be exactly the same. When is the problem dynamical? It will be dynamical when: firstly, the heeling forces, in consequence of doing the work of heeling, undergo a change; for example, in the problem: A projectile of the mass m strikes with the velocity v, how far will the ship heel? Secondly, every problem is in fact dynamical for the actual vessel endowed with mass. But, if a final position of a system of forces is required, the problem can, practically, be assumed as a statical one, as the oscillations of the vessel resulting from the smallest velocity of mass soon assume, practically, the position of equilibrium. Let us reconsider the above problem of the squall for an actual vessel. In this case the solution must, first, find the statical position of equilibrium, and then the velocity with which every molecule of the ship goes through this point of equilibrium. The *vis viva* given herewith will continue to heel the ship till it is entirely consumed by the resistance to heeling, by skin friction, the bilge keels, &c. To equate the product of wind pressure, multiplied by the distance through which it has moved, with the work of heeling (Schmidt, "Stabilität von Schiffen") is absurd, as also is the nice result

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that the angle of heel for sudden wind impulse equals twice the angle of statical equilibrium. Sir W. White gives in his manual, as an example of the difference between the statical and dynamical action of wind pressure, the deadweight on a spiral spring, and then a sudden impact on the same. The example would be correct if the wind were an enclosed mass which could communicate its whole power of doing work to the vessel, and, at the same time, lose its own velocity. I should rather substitute, in the example, for the spiral spring an ordinary thin flat spring, fastened at one end, against which a mass, great comparatively to the spring, is thrown. The spring will then bend and let the mass pass over it. The work which is done by the mass, from the time of touching the spring till it has left it, is, by no means, taken up by it, only in so far as the mass m of the spring, and the velocity of each of its molecules at the moment when the mass leaves the spring, constitute the work $\frac{m v^2}{2}$. This work will be used to further bend the spring. A similar treatment as in the case of wind pressure may be applied to the inertia of water, if the mass of the water doing the work is so great that we cannot speak of a loss of velocity due to the heel; that is to say, if the molecules of water which lose velocity in order to transform it into work are constantly accelerated by a sufficiently large mass of water. The explanation given may be sufficient to show how the forces under (3) enter into the problem of stability, and to enable us to avoid misunderstanding it. A third objection has been raised respecting the transformation of co-ordinates in the general problem of stability. Professor Kriloff recommends, instead of the determination used by me of the position of the first system in respect to the second system, (1) the application of the Eulerian determining triangle, especially the application of the determining parts given by Euler to define the triangle (see Fig. 2, Plate XXXV., of Professor Kriloff's paper, "A General Theory of the Oscillations of a Ship on Waves," or Fig. 1); (2) of the different possible positions of this determining triangle he recommends especially the position chosen by him (see Fig. 3, Plate XXXV.). Let us investigate these propositions in a more detailed manner. The position of a rectangular system of co-ordinates in space in respect to a second one with the same origin of co-ordinates is fixed in a simple manner by any spherical triangle, which is formed on a sphere round the origin of co-ordinates, by the angle between a plane of co-ordinates in the initial and the final position, and by the two angles round which the system is turned in the two planes. It must be possible to express the nine co-efficients, which characterise the position of the systems in the formulæ of transformation, by any three determining parts of this spherical triangle. I quite agree, as a practical naval architect, with Professor Kriloff in respect to the sentence that the choice of the determining spherical triangle must be made from a practical point of view; and I go still further, maintaining also that the choice of the determining parts of this triangle depends only upon the particular problem. First, which position of the spherical triangle is the most useful for our special purpose? The problem of the statical equilibrium of a vessel is entirely independent of the motion of the same in the $\xi\eta$ plane, that is to say, of the motion of the vessel in the plane of flotation (see Condition VI., page 213). We, therefore, will choose the spherical triangle in such a manner, that one side is in the $\xi\eta$ plane. This part is eliminated from our problem, and there remain only two elements sufficient to fix any position of the ship in respect to the plane of flotation. The position of our spherical triangle will be, therefore, the same as that of the Eulerian triangle A B N (see Fig. 1, Plate XLVIII.). Which determining elements are to be chosen in this triangle? We may choose these parts as Euler does (see Fig. 2, Plate XLVIII.): (*a*) We turn the system round the ζ axis by the angle ψ; (*b*) we turn round O N by the angle θ, then the $\xi\eta$ plane coincides with the X Y plane; (*c*) we turn round the Z axis by the angle ϕ. Three other determining elements would result, for example, from the

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following motion (Fig. 3, Plate XLVIII.):—(*a*) We turn round the ζ axis by the angle ψ_1; (*b*) we turn round the axis ξ, by the angle ϕ_1; (*c*) we turn round the X axis by the angle θ_1. Then the $\xi\eta$ plane coincides with the X Y plane. There is an endless number of possible motions, especially if, following Euler's example, we change from three determining elements to four. For our general problem of statical stability, which we treat with respect to the practical considerations repeatedly mentioned, the following motion is chosen (see Fig. 4, Plate XLVIII.):—(*a*) Turning of the system round ζ axis by the angle ψ_2; (*b*) turning round an axis η_1, perpendicular to $O N_2$, and lying in the $\xi\eta$ plane at the angle ϕ_2; (*c*) turning the system round $O N_2$ by the angle θ_2. The turning round the ζ axis does not enter into our special problem, therefore we have only to deal with the motions given by (*b*) and (*c*); that is to say, two determining parts ϕ and θ. It is absolutely necessary to define exactly the axis and the order of revolution, criticised by Professor Kriloff, and by remarking that, should one choose the Eulerian angles, one avoids this determination only so far as one causes Euler to speak for himself. The values $\psi, \phi, \theta, \psi_1, \phi_1, \theta_1$, &c., are connected by relations derived from the positions of the separate parts in the spherical triangle. I am quite sure that Professor Kriloff, following these considerations, will agree with me in:—(1) That I did not introduce three determining elements, neither the Eulerian elements, nor any other three, by which I should have necessarily, quite needlessly, taken in condition VI., page 213; (2) that, therefore, I do not join in the choice of the Eulerian triangle defined by Professor Kriloff; (3) that, if I take the same triangle for getting the same formulæ in the two problems of Professor Kriloff and of myself, I would always define the angles chosen in the manner illustrated by Figs. 5 and 6, Plate XLVIII. The formulæ for our problem can be derived in the last case, for example for Fig. 5, from the formulæ given in Professor Kriloff's paper by making $\phi_3 = 0$. I hope, lastly, not to have slighted Euler's genius by using special determining elements of his triangle, that is, to say, a special manner of forming the triangle. Other problems require other solutions, and Euler himself did not sin against his own genius by giving us in another solution four instead of three determining elements still more unserviceable for us. My proposition to replace the linear measure of the metacentric height as a measure of initial stability by the initial angle of the curve of lever arms was not favourably received by Professor Kriloff. I repeat what led me to this proposition. The problem of stability has for its object to investigate the conditions of equilibrium between any given forces acting on the ship and the forces of buoyancy, for finite motions. This can only be done by the use of the conditions of equilibrium already developed, in which the moments of buoyancy are equated with the moments of the other forces. In all the problems the moment of buoyancy must be included. The moment still remains if we divide the value $G \cdot a$ by $\sin a$; we thus obtain $\frac{G \cdot a}{\sin a}$; $\frac{a}{\sin a}$ represents the value which, in France, characterises the position of the metacentre (shifting metacentre, metacentre at given angles); that is to say, we obtain in the perpendicular going through the centre of displacement in the initial position (to be taken as fixed to the ship) the segments, which are formed by the perpendiculars through the origin of co-ordinates and through the centre of the displacement for a given angle. For the special case, which alone has been treated up till now, $a = 0$, and for $a = 0$,

$$\frac{G \cdot a}{\sin a} = \frac{0}{0}$$

The determination of this expression brings us to the well-known value = I = moment of inertia of the original water-line. The definition of the metacentric height in the problem of stability is only then correctly expressed when it is derived from $\frac{0}{0}$: this has not been done up till now, and for this

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reason alone I would confirm the sentence quoted from my paper by Professor Kriloff. All investigations which take the metacentric height as the radius of curvature of the curve of displacement can never go further than for an infinitely small motion; because, only for such a one, as has been already mentioned on page 222, $\frac{a}{\sin a}$ and the radius of curvature coincide. The investigation of an infinitely small motion in practice is insufficient. In the problem of stability three quantities come into relationship to each other, a, t, and G or M; they represent mathematically a surface. The curve of moments, from which the curve of lever arms is derived, only represents the curve of intersection of a plane with this surface. Further, the value $\frac{I}{V}$ (Professor Kriloff) gives only the property of a single point on the curve of lever arms; that is to say, in the most limited manner, the property of a single point of the surface, which we must necessarily know completely in order to form a judgment of the stability. As long as one was satisfied with defining a surface by the properties of a single, or of a few separate points, how could we speak of a correct manner of regarding the forces, even if theoretical and practical people were not at all decided how these properties are to be illustrated? This illustration, that is to say, the concrete translation of the metacentric height in connection with the curve of lever arms, was first given by Professor Jenkins. The investigation due to him of the property of the lever arm curve expressed by the definition of the metacentric height is absolutely necessary for clear perception. To require abstract thought or extensive mathematical demonstration in practical life is impossible, or would be dangerous. That I can refer, as far as the dangers of the definition of metacentric height is concerned, to the judgment of a man like Sir Edward Reed—viz., his above-mentioned paper—is a great satisfaction. Sir Edward Reed has expressed also the wish for an international regulation of the question. Lastly, Professor Kriloff wishes to find out more details of the calculations. I have nothing more to add to the data on pp. 224—226. The statements there given are detailed enough to enable a direct numerical calculation for any ship to be made. The determination of the values required for ordinary stability calculations does not differ from the old one, and can be solved by one of the many methods sketched on p. 218. I repeat, the advantage of drawing the diagrams consists in that all the data of the calculation are made use of to judge stability. I am sure it would be an easy and fruitful task to compile graphically in this complete manner the results which have been collected in old calculations of stability, and thus to get directly, without any new calculations, a series of surfaces, the form of which would give us insight into the influence of form on stability, and the systematic comparison of which should be the subject of all future investigations for advancing the problem of stability.

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MINIMUM NET REGISTER, AND ITS EFFECT ON DESIGN.

By A. G. Ramage, Esq., Member.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, April 1, 1898; Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President, in the Chair.]

In the palmy days of ship management, a few tons more or less net register were no great matter, but competition is now forcing owners to consider everything by which a few pounds may be saved, and, of late, tonnage has come in for its share of attention; and, when we consider the difference which can be made by proper design to the cost of working vessels, especially on short voyages, it will be seen that the subject is well worthy of the attention of managing owners.

It is no uncommon thing nowadays to see in the Register Book the S.S. so and so, with a ratio of gross to net of 2·706, whilst some reach 3·49.* A, B, and C on Plate XLIX. are vessels of the same dimensions and similar arrangement.

A's	gross is	949	and net	493.	Ratio 1·924.
B's	,,	951	,,	401.	,, 2·371.
C's	,,	952	,,	371.	,, 2·566.

Such figures catch the eye of the managing owner, and he hastens to inquire why his vessel, now building, has not a proportionately low net register. I have sometimes heard owners express indignation because builders had not done the best possible for them in this direction.

I think, therefore, that a brief survey of the Tonnage Act, and a consideration of the vital parts affecting the net register, and the result to the general usefulness of the ship of aiming at a low net register, may not be unprofitable.

Bearing in mind that nothing can be deducted, which has not been added to the gross, we shall consider the principal deductions, and how they may be augmented.

The most important part is generally the engine-room. If we can make this up to 13 per cent. of the gross tonnage in a screw steamer, we may deduct 32 per cent. of

* Vessels with this high ratio are usually coasting vessels, with their engines aft, and a raised quarter-deck carried over the machinery space.

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the gross, and in screw vessels wherein the engine space is 20 per cent. of the gross tonnage, we may deduct $1\frac{3}{4}$ times the actual propelling power space.

We have therefore to consider which is larger—32 per cent. of the gross, or $1\frac{3}{4}$ times the actual propelling power space.

The propelling power space consists of the following parts :—

(1) Actual engine room.

(2) Shaft tunnel and recesses.

(3) Donkey recess.

(4) Light and air space (by application).

In the smaller class of vessels fitted with triple-expansion engines, it is generally possible to achieve the 20 per cent. deduction. To do this we must make the most of 1, 2, 3, and 4.

Taking No. 1, the actual engine room, we could make this larger in a one-deck vessel by extending a raised quarter-deck over the engine room, or by reducing the side coal bunkers to a minimum.

No. 4 we can increase by fitting the casings as large and as wide as our deck arrangements permit of.

The boiler casing might be made wide enough to admit the boiler. Now, if the side bunkers be reduced, space must be found elsewhere for the coals, under the bridge deck or on top of the bridge deck, as was the case in the vessel, the plan of which is marked A, portable boards attached to stanchions being fitted to hold them.

The stability must be considered in adopting this plan. The engine room can, of course, be brought up to the required percentage by sacrificing the hold space, and there is no doubt that, in certain trades, this can be done profitably.

The question how far this may be carried is one for the owner to decide. It is obvious enough that, if the bulkheads of the engine space be moved further and further apart, and the deduction is made of $1\frac{3}{4}$ times the actual engine space, the tonnage might be reduced to zero.

In deadweight trades, and for timber carrying with deck loads, a large engine-room may effect a saving of hundreds per annum. I have heard a managing owner declare that each ton of reduction on tonnage meant £2 per annum of profit.

For general purposes, however, it is not wise to unduly enlarge the machinery space, and, obviously enough, the saving effected on the tonnage might easily be spent in trimming coal down into small pockets in the stokehold.

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It is easy to see that the tendency of the part of the Act relating to the measurement of engine spaces is toward large engine-rooms and high casings, both of which, from a sea-going point of view, are desirable within limits; but, the ship intended for general purposes, which may be carrying bulky cargo one voyage and weighty cargoes another, requires all the cubic capacity of the hold which can be got. Such vessels may be sent to ports where coal is not readily obtainable, so that for such vessels minimum net register, obtained at the expense of hold and bunker space, would not be profitable.

The next deduction in importance is that for crew's space.

In arranging crew space for minimum tonnage, we should obviously secure as deductions such parts as are of least importance from a money-earning point of view.

The part of the ship below the main deck before the collision bulkhead is of little use for stowage, and only a portion of it could be deducted as a boatswain's store. The crew may be put here, and the net register is lowered. The top-gallant forecastle will be treated as exempt, provided no doors be fitted to the bulkhead; by fitting, however, a small locker just beside the openings, with a door which can fold back over the opening, utility is satisfied and the law evaded.

A bridge house, poop, or deck house may be made an exemption also by leaving off the doors; should cargo, however, be carried in such spaces, surveyors are authorised to measure spaces occupied by it, and add the tonnage of such spaces occupied, for the time being.

Something also may be saved by the judicious naming of the different apartments of the cabin in cargo steamers.

The saloon must be called the mess-room, spare state-rooms must be dedicated to imaginary officers.

By a recent dispensation, peak ballast tanks may be exempt from measurement, provided the following rules be conformed to :—

(1) That the space is not available for cargo, stores, or fuel.

(2) That the space is of sufficient strength to resist the pressure it will be subject to, should the shell in way of it be perforated, the top being of course made tight, iron to iron.

(3) That a figured plan and profile of the space be sent to the surveyor.

(4) That the space is entered by an ordinary sized oval manhole only.

(5) That the top of each space is not more than one foot above the deep load-line of the vessel at her usual trim.

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This last clause leads to, what seems to me, a hardship in vessels with raised quarter decks.

K, Fig. D, Plate XLIX., shows such a vessel. If the tank flat be placed one foot above the water-line a small space good for nothing is left. If the flat be kept down far enough to make this space useful as a store, there is little reduction on tonnage, as the vessel is narrowing rapidly, while there is a serious loss of water ballast where it is most needed.

I think this enactment requires amendment. While on the subject of ballast tanks, I would direct your attention to the vessel shown on diagram D. This vessel was built to carry coal to Hamburg from the Forth, and was designed to make two voyages per week, coming back in ballast. With this in view, a tank 9 ft. deep was fitted under the after holds, and the tonnage is measured to the tank top only. The Board of Trade demurred to this when the plans of the vessel were submitted, declining to consider the flat as an inner bottom in the meaning of the Act. The owners of the vessel, however, took the matter up, and, supported by the opinion of counsel, showed that the Act was open to this interpretation. Only one manhole was fitted to each compartment of this tank or deep double bottom, so that it could not be used for cargo.

Had the owners not carried their point, this vessel would have been placed at a serious disadvantage in the trade for which she was designed.

With a view to reducing the under-deck tonnage, the tank top is sometimes made to rise towards the sides, with a view to reduce the length of the bottom ordinate of the under-deck tonnage, but the game is not worth the candle.

Large "tumble home" toward the deck is sometimes resorted to, and with reason, for a portion of the vessel which is rarely stowed may be removed, but the vessel suffers as a deck carrier.

It is not worth while, in general, to attempt to reduce the tonnage of old vessels which have been designed without regard to this matter. Taking down the side bunkers, altering light and air spaces, fitting up other bunkers, must necessarily involve considerable outlay, while the surveyor would not improbably insist, at the re-measurement, on all the requirements of rules made subsequently to the former measurement being complied with.

There is some comfort for builders in this reflection.

To return to the subject of large machinery spaces, it was suggested to my firm, with a view to getting a large machinery space deduction without encroaching upon the hold space by unduly lengthening the engine room, to carry a raised quarter-deck forward over the engine and boiler space, with a bridge-house upon it and high casings

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on top of that again. Lloyd's, however, refused to class what would have been a most promising tonnage-cheater, and the matter went no further. Had this vessel been built, the cost would have been much increased by this ruse. This vessel is shown in Figure E, Plate XLIX.

The judicious location of the boatswain's store may enable us to get a deduction of some space, on which, under another name, we should have to pay dues.

As a general principle it appears just, that space not actually used for cargo carrying should not be included in the tonnage on which dues are paid; but, it must be borne in mind that the rule for engine-room measurement and deduction favours vessels in deadweight trades, and punishes those engaged in bulk trades; it favours the shipbuilder, however, inasmuch as it tends towards specialisation. It is therefore a wise Act.

DISCUSSION.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Gentlemen, you will agree with me that this paper is a very interesting one, and I will ask Mr. Martell to open the discussion.

Mr. MARTELL: Hearing that there is a representative of the Board of Trade here, I would rather hear first his opinion with regard to the paper, and perhaps Mr. Macfarlane Gray would favour us.

Mr. J. MACFARLANE GRAY (Member of Council): There have been many anomalies in the application of the tonnage rules. The first vessel measured by me, in 1868, when a surveyor, gave a negative net register tonnage. It was a paddle tug-boat, with the engine-room more than two-thirds of the gross tonnage. The same result would be obtained with the rule as it stands to-day. I think now that I wrongly applied the rule. I discovered afterwards that in the rules the word "deduct" is always employed in its strictly proper sense, meaning "to lead away from," "to separate," "to remove," "to set apart." It is only in a secondary sense that "deduct" means "to reduce by a stated amount" as in arithmetical subtraction. In the *Isabella* case certain spaces were, by the rule, to be "deducted" from the tonnage. They were accordingly from the first "set apart" from it, and never included in its calculated amount. The shipowner afterwards claimed that they should be again deducted from the register tonnage, again "led out" or "withdrawn" from an amount in which they never had a place. The right to do this, by an arithmetical fiction—for it would have been a miracle to do it actually—was successfully maintained at law, until a special Act of Parliament was made to restore the original sense of the rule, which had from the first been quite correctly expressed.

Mr. B. MARTELL (Vice-President): Sir William White and Gentlemen, I feel a good deal of difficulty in making any remarks on this paper, because I scarcely know how to discuss it, whether from a technical or a moral point of view. I certainly must give Mr. Ramage a great deal of credit for his courageousness in producing such a paper as this. Mr. Ramage has shown us in his paper

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how the law can be evaded—not that their firm would do such a thing for a moment. I cannot believe that the firm of Ramage & Ferguson would adopt any of these devices, but this shows how such things can be done. Whether it will enlighten the Board of Trade and lead them to adapt their rules so that the correct cubical capacity of vessels can be obtained, and to see how they cannot be evaded, I cannot tell; that is a matter for their consideration. They are able to take care of themselves in a way. There is no doubt that the draughtsmen in various establishments, who have not that versatility of mind and intellect to discern all these points that can be taken advantage of in this way, will derive a great deal of benefit from this paper; but I very much fear the generality of them are too conversant with what Mr. Ramage has told us. However, there is one point I wish to refer to, because the name of the society I have the honour to represent is mentioned in regard to it. It was, in submitting the plans of the vessel referred to for approval, playing the game a little too high. I am glad that the principal technical officers of Lloyd's Register Society, who, we expect, ought to be acquainted with these ruses, were so, as is evident in this instance. Here is a vessel (Fig. E, Plate XLIX.) where you will see there is a raised quarter-deck carried for nearly the whole length of the ship, and I must say that I was somewhat astonished that Mr. Ramage had so little appreciation of the ability of Lloyd's surveyors as to think that they would possibly omit taking notice, or that they would sanction a vessel of that kind being built with scantlings taken to an imaginary depth, and thereby produce a very much lighter vessel than a similar vessel built exactly to those rules, and carrying consequently a very much larger amount of cargo. Now, of course, we were obliged to say that the rules did not contemplate a vessel being built on such scantlings as these, and it was not done. I daresay that some, perhaps Mr. Ramage himself, thought we were acting rather hardly. We are often twitted, you know, with being rather obstructive, and that we do not allow these innovations—these *improvements*—to take place to a sufficient extent; we stop such things, and therefore we are designated as obstructives. I think if we were obstructives in such an instance as this we need not condemn ourselves very much for having that form of reproach cast upon us. I do not know that I have a great deal more to say on the subject. There is no doubt that any kind of general rules that can be made are liable to be evaded by a very intelligent mind applied to them. But I have no doubt that the generality of shipbuilders, although they like naturally, from the competition they have with others, to produce the most profitable vessels they possibly can, in their own interests and the interests of the owners, do endeavour to carry out the rules that are framed by the Government in the spirit in which they are intended, that is, that spaces made for freight-earning purposes should be measured and included in the tonnage.

Mr. John Inglis, LL.D. (Member of Council): Mr. Ramage says on page 240, "A bridge-house, poop, or deckhouse may be made an exemption also by leaving off the doors." I daresay that may be true in a general way, but the Board of Trade seem to reserve a discretionary power to add such erections to tonnage if they think proper. I am aware of two vessels which have been running some years with deck saloons having no doors. These erections were not at first included in the tonnage, but recently they have been measured and added to the tonnage of the ships. Similar vessels are now building, and they are to have the tonnage of the saloons included. I think this discretionary power is absolutely necessary to the Board of Trade to ensure a fair and proper application of any tonnage law whatever; because, as Mr. Martell says, the wit of man can hardly devise a law that the wit of some other man cannot contrive to evade. One of the anomalies in connection with shipping legislation may here be mentioned. On account of a comfortable smoking-room having been built on deck for the use of first-class passengers, although the vessel is not thereby enabled to carry any

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additional passengers, and does not therefore require any addition to the crew, she is obliged to carry two additional lifeboats or equivalent life-saving appliances.

Mr. Henry Withy (Member): I did not intend to make any remarks on this paper, but it differs so much from those which we generally hear, and those which we have heard to-day, that I think it is worth some discussion. Mr. Ramage appears to begin with the assumption that it is always profitable to reduce the tonnage. I know of many cases in which it is not, especially where ships are chartered on the net tonnage. It is also in some cases a disadvantage to shipbuilders. In two cases I have paid attention to certain points, and have been enabled to bring out rather a small tonnage, and I was met with a claim from the owners for compensation because the ship was not as large as the previous ship they had, though it was of the same dimensions. It was rather a difficult matter to show the owners that the ship was really as good, although the tonnage was less. The devices that Mr. Ramage suggests in many cases I know are practised, but some that he suggests would not, I think, for a moment be allowed by the surveyors in our district; in fact, I never heard of them before. He says, "The top-gallant forecastle will be treated as exempt provided no doors be fitted to the bulkhead; by fitting, however, a small locker just beside the openings, with a door which can fold back over the opening, utility is satisfied and the law evaded." I think the door would be of very little use, and I do not think tonnage would be affected by it. I do not think that a long discussion on the tonnage laws will do much, because, whatever the law may be, there are legitimate ways of making the most of the tonnage, or the least of it; and I do not think dock companies, for instance, care very much about it, as they make their money on the cargoes. The shipowner wants capacity, as a rule, unless he is in the ore trade or some other deadweight trade, and if he wants capacity he ought to be willing to pay for tonnage. What I think shipowners have to complain of most is the difference of practice in different ports. I have shown you one—the door by the forecastle. Mr. Ramage refers to the peak tanks. The exemptions he gives do not correspond with what are used in our district. I never heard before that the top of these spaces should not be more than one foot above the deep load-line. There are matters in regard to boats. You probably all know that in one port you can have your lifeboats fitted with air-tight tanks made of copper, in another port with galvanised iron, and in yet another port with wood. All these things want putting right; I do not think there should be quite so much left to the discretion of the surveyors.

The Chairman (Sir William White, K.C.B., LL.D., ScD., F.R.S., Vice-President): There seems to be a disinclination on the part of any other shipbuilder to give us further information. Whatever view may be taken of the paper by the members present, I am sure that it has somewhat enlivened the close of a day in which mathematics have been heavy in the air. If the late Mr. Moorsom still continues his interest in tonnage measurement he must be immensely surprised to find that the law which he framed in 1854 has succeeded so well, and lasted so long. Having followed pretty closely the history of the work he did before the Act of 1854 was passed, and the amendments made since, I do not think Mr. Moorsom could have anticipated that the principles he then succeeded in establishing would have continued in operation until the period when we are now discussing them.

Herr C. F. Laeisz (Associate): Well, Sir William, we used to follow a different principle in endeavouring to arrive at the real measurement, but we found our vessels were so severely handicapped that we had to adopt the English system. I am not certain that the Act is such a wise one, and whether it leads to producing a good seaworthy ship of the best sea-going qualities, and whether it has not a tendency to lead shipbuilders to construct vessels more approaching monsters than good sea vessels.

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Mr. F. Edwards (Member): Sir William White and Gentlemen, I had no intention of speaking, but Mr. Macfarlane Gray thinks you might like to have the following information with regard to the old Jersey steamers which used to run from Weymouth in connection with the Great Western Railway. I made certain alterations, and so reduced the tonnage that the saving was at the rate of £600 a year in the winter and £1,000 in the summer. We were wondering whether we could still further reduce it. There were spaces under the saloons, and we discussed this point several times, and the question was raised as to whether we could use these places for lavatories or purposes of that sort, but we had ultimately to give that up. The Act read rather curiously, it said that the extreme dimensions if multiplied together shall be *deemed* the cubical capacity. It seemed to me to read as if it was intended that advantage would be taken of that point.

Mr. J. Macfarlane Gray (Member of Council): I understand that, in this case, the spaces deducted happened to be of a form which, when calculated for capacity by multiplying together the extreme dimensions in length, breadth, and height, gave a product much in excess of the actual volume. Three 10 ft. lengths of inch pipe laid across each other might in this way be calculated to be 1,000 cubic ft. capacity. The present tonnage rules prescribe that the "mean" dimensions shall be employed in calculating the volume. Of course, if the rule dictate that the extreme length, breadth, and height should be multiplied together and taken as the volume, it would be quite proper to so apply them to the advantage of the shipowner. I cannot find any opening admitting this in the present rules.

Mr. Richard Ramage (Member): Mr. Chairman and Gentlemen, I have very great sympathy with the Board of Trade surveyors and shipbuilders. I do not think any of those evasions we hear about being made originate with shipbuilders. I should just like to ask Dr. Inglis if the spaces which he has referred to as measured in were not for a very large period of years earning money for the owners. I think in that case they would be very justly charged in the tonnage. I think any space that is earning money should be charged in the tonnage, but in bridges alongside of passages, or machinery, which are open, and where perishable cargo cannot be stowed, then I say they are justly uncharged. I should like to ask Dr. Inglis, were these places money-earning, or not, during that time?

Mr. Inglis: It was a saloon for first-class passengers.

Mr. Richard Ramage: Then they were earning money, and ought to be charged.

Mr. A. G. Ramage (Member): Sir William White and Gentlemen, in spite of Mr. Martell's assertion that the materials of this paper are matters of common knowledge, I do not think I need to apologise to this Institution for bringing under its notice these few notes on tonnage; because, although tonnage measurements are carried out in conformity with Acts of Parliament, the subject is not, on that account, fixed permanently. In my district, at least, a growing desire has lately been evinced to interpret the Acts in the most liberal way, and I know that many points have been raised and settled locally which form precedents. It sounds very well to talk of carrying out laws "in the spirit." I, for one, think that Acts should be made the most of. Such treatment serves to sharpen the wits both of those who make the laws, and of those who have to work under them. I need not say I have no sympathy with "ways that are dark and tricks that are vain." I am sure you will agree with me that a good deal of ingenuity has been displayed lately in connection with the tonnage laws. Most of the vessels built within the last few years exhibit their influence in some degree. Some types owe their existence to them. One point, however, I wish to emphasise; it is, that low net tonnage does

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not in all cases mean an economical vessel to work. In striving after this owners may jeopardise not only the general usefulness of their vessel, but also the comfort of officers and crew. In conclusion, I wish to state that I am at one with Mr. Martell on the wisdom of Lloyd's in refusing to class the vessel shown by Fig. E. Although the plans were put forward by my firm, it was at the request of a client, and although doubtless she would, if she had been built, have done her work, she is not a wholesome type of ship. Sir William White and gentlemen, I thank you for the hearing you have given me.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): I ask you, gentlemen, to express your thanks to Mr. Ramage for this interesting paper. We will then adjourn till seven o'clock, when some very interesting papers are to be read, and when the concluding proceedings will take place.

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THE STEERING QUALITIES OF THE *YASHIMA*.

By PHILIP WATTS, Esq., Member of Council.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, April 1, 1898; Admiral the Right Hon. Sir JOHN DALRYMPLE-HAY, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

THE design of the *Yashima** was discussed and approved in 1893. She was to be a first-class battleship of about 12,000 tons displacement, carrying four 12 in. guns in pairs in barbettes, and ten 6 in. guns. She was to be protected at the water-line by an 18 in. belt of hard steel armour, and was to have great speed and great manœuvring power. She was built from December 1894 to July 1897 at Elswick shipyard.

The dimensions of the vessel are given on Table I., and I have here photographs of the completed ship, and a rough elevation and plan showing the distribution of the

TABLE I.

DIMENSIONS OF "YASHIMA" AND "THUNDERER."

	Yashima.		*Thunderer.*	
	Ft.	In.	Ft.	In
Length of under-water body	412	0	307	0
,, between perpendiculars	372	0	285	0
Breadth, extreme	73	9	62	3
Draught forward	26	3	25	6
,, aft	26	3	27	0
,, mean	26	3	26	3
Displacement	12,300 tons.		9,330 tons.	

armament and the arcs of training of the guns, the extent of the armour, the various compartments, &c., which show at a glance the general features of the vessel (Plate L.

* Japanese battleship, built by Sir W. G. Armstrong, Whitworth & Co., Ltd.

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and Fig. 1, Plate LI., respectively). The length of her underwater body is 412 ft., her breadth is 73 ft. 9 in., her draught is 26 ft. 3 in. throughout, and her displacement is 12,320 tons with all normal weights on board, including 700 tons of coal, out of a total of 1,200, which is the full bunker capacity. Besides the above armament, she also carries twenty-four 3 pr. guns, four submerged torpedo tubes, and one above-water tube. Of the ten 6 in. quick-firing guns which she carries, four are placed on the main deck in casemates, and the remaining six on sponsons on the upper deck. Her armour is steel treated by the Harvey process. The main belt extends sufficiently far forward and aft to include and protect the bases of the barbettes; over the machinery spaces it is 18 in. thick, and beyond these it is reduced to 16 in. and 14 in., and terminates in armour bulkheads across the ship, the forward one being 14 in. thick and the after one 12 in. thick. A 2½ in. protective deck is worked from end to end at the level of the upper edge of the belt over the belted portion, and a few feet below the water level before and abaft the belted portion. Its position throughout is indicated on the elevation (Fig. 1). Above the belt, to the height of the main deck, and between the barbettes, the sides of the vessel are protected with 4 in. armour. The two barbettes, upon which the two pairs of 12 in. 49-ton guns are mounted, are protected over their upper parts by 14 in. armour down to the main deck, and by 9 in. armour below the main deck down to the protective deck, and each pair of guns is protected by a gun-house of 6 in. armour. The four casemates for the 6 in. guns on the main deck are protected with 6 in. armour, the other six 6 in. guns being protected with strong shields carried by the mountings. The conning tower is of 14 in. armour. The main propelling machinery was constructed by Messrs. Humphrys, Tennant & Co., and consists of twin-screw vertical triple-expansion machinery, of which the cylinders are 40 in., 59 in., and 88 in. in diameter respectively, and the stroke 3 ft. 9 in., and which are supplied with steam from ten cylindrical boilers of the ordinary single-ended return-tube type. The contract provided that the horse-power was not to fall short of 10,000 with open stokeholds, nor 13,500 with forced draught. On her speed trials the vessel ran with open stokeholds for six hours at a mean speed of 17·26 knots, and made four consecutive runs with and against the tide on the Admiralty measured mile at a mean speed of 17·73 knots. With forced draught (1½ in. of air pressure) she ran for four hours at a mean speed of 19·227 knots, and made four consecutive runs with and against the tide on the Admiralty mile at a mean speed of 19·46 knots.

What I wish to bring before you, especially, this evening is the steering qualities of the vessel.

In 1877, at the suggestion of the late Mr. William Froude, I was entrusted, for the information of the *Inflexible* Committee, with experimental investigation for determining the extent to which ships would heel in turning under the action of their rudders; and it occurred to me to take advantage of the opportunity for accurately

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plotting the curve traversed by a ship under the action of her rudder, and the position of the ship at each instant with reference to this curve. The experiments were made off Portland with H.M.S. *Thunderer*. The ship was made to turn under various circumstances, at different speeds, and at different helm angles, also with one screw going ahead and the other going astern, and with both of the screws going astern.

The position of the ship was fixed at numerous intervals with reference to a floating object within the circle, or curve, in which she turned, by observing simultaneously the direction of her head and the angles at the base of a triangle whose apex was the floating object and base the line between two observers at fixed points on the deck, one forward and the other aft.* By placing the data obtained in curves to a time base, the position of the ship at any instant throughout the motion could be at once determined.

Certain of the cases investigated were given in my report to the *Inflexible* Committee, and will be found in Appendix VIII. of that report.

The particulars of the *Thunderer* are given on Table I., by the side of those of the *Yashima*, and on Fig. 3, Plate LII., is given the track traversed by the *Thunderer* under the action of 31° of helm, at an initial speed of 10½ knots, with the outline of the ship at various intervals upon the track.

I may mention that a further and very complete series of turning trials was afterwards made with the *Thunderer* by her Captain (now Admiral) Colomb, and was described by him at the meeting of this Institution in 1886.

Amongst other important facts the experiments with the *Thunderer* demonstrated (first) that a ship in turning under the action of her rudder places herself so that her bow is nearer to the centre of the circle or curve in which she turns than her stern; that she may, in fact, be regarded as going ahead and turning or pivoting about a point well forward in her middle line, the middle line being, at this point, a tangent to a circle concentric with that in which her centre of gravity is turning; and (second) that the greater the rudder angle, that is, the greater the turning couple, the further forward this *pivoting point* will be situated, and the smaller the circle turned through will become.

It was evident from these experiments that the turning power of a ship might be increased by removing or partially removing the after deadwood, which, on account of its distance from the *pivoting point*, was very resistful to turning; and immediately after the trials I proposed to my chief, Sir Nathaniel Barnaby, an arrangement by which the whole of the deadwood up to the level of the line of shafting might be removed, the rudder being balanced by being carried forward below in the space from which the

* I was not aware, at the time of the *Thunderer's* experiments, that this method had previously been adopted at turning trials in the French Navy

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deadwood was removed. This arrangement was considered open to certain objections, and it was not adopted until some time afterwards, when, in a modified form, it was adopted in the *Polyphemus*.

Going to the case of the *Yashima*, practically the whole of the after deadwood is removed, and a very large balanced rudder of the type described above is fitted. The main propeller shafts are allowed to run bare, thereby offering less resistance to turning. In these respects she is similar to all other Elswick-built ships of recent years. These features will be seen from the profile (Fig. 2, Plate LI.). The form of the ship may be described as one in which the average transverse section forward is very U-shaped, and the average transverse section aft is unusually Y-shaped and very fine, the bilges being very flat. The bilge keels of the vessel also were placed well forward, so as to favour turning.

Observations were made on the turning of the *Yashima* on several occasions, but the official turning trials were made on July 14, 1897. Experiments were made with various helm angles, the initial speed of the ship being in each case 17½ knots. The data obtained from three of these experiments are given in Table II., and Fig. 4, Plate LII., shows the track traversed by the ship under the action of 32° of helm. The difference between this survey and the corresponding survey for the *Thunderer* (Fig. 3) is very striking.

TABLE II.

RESULTS OF TURNING TRIALS OF "YASHIMA" AND "THUNDERER."

Ship.	Helm Angle.	Diameter of Final Circle Traced by Pivoting Point.	Diameter of Final Circle Traced by Centre of Gravity.	Tactical Diameter.	Time Occupied in Turning through 180 Degs.	
	Degs.	Ft.	Ft.	Ft.	Min.	Sec.
Yashima ...	5	1,180	1,236	1,230	1	29
	10	1,050	1,114	1,095	1	26
	32	800	880	830	1	20
Thunderer ...	31	1,240	1,250	1,315	2	50

The *pivoting point* in the *Yashima*, when the ship was moving with the rudder hard over, proved to be almost exactly at the stem of the vessel, and the tactical diameter was approximately twice the length of the vessel; whereas, in the *Thunderer*, the *pivoting point* was some 50 ft. abaft the stem, and the tactical diameter was 4¼ times the length of the vessel.

In dealing with turning trials, I think it preferable to note the curve described by the *pivoting point* than to note the curve described by the centre of gravity of the vessel, because the tangent at any point of the curve described by the *pivoting*

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point indicates the direction in which the ship is advancing in a fore and aft sense, when her middle line is coincident with this tangent, and it is therefore the curve with which we are concerned in most manœuvring problems. Thus, when the helm of the *Yashima* is put hard over, which, I may mention, can be done in eight seconds, the *pivoting point* traverses a curve which approximates pretty closely to a circle after the ship has turned through 360°; and after she has turned through 180° the tangent to the curve at the *pivoting point* will be parallel to the original course, and the distance between these two lines, that is, between the middle line of the ship after she has turned through 180°, and the original course of the ship produced is called the tactical diameter. If it were only intended to reverse the course of the ship, it would be the duty of the helmsman to ease his helm and check the vessel just before she has turned through 180°, so as to enable her to proceed on the course exactly parallel to her original course.* But the curve traced by the centre of gravity of the vessel, which is shown on Fig. 4, Plate LII., by the dotted line, will lie quite outside this course.

The curve, however, in which the ship, considered as so much matter, must be regarded as moving is the curve in which her centre of gravity moves, and this must be taken in all dynamical problems, such, for instance, as have to do with the heel of the vessel, the instantaneous axis about which the ship is turning being the centre of curvature of this curve at the point occupied by the centre of gravity.

One remarkable feature in the steering of the *Yashima* was the almost entire absence of any tendency to deviate from a straight course. When the helm was amidships the vessel would often run for a considerable time on a straight course without the helm requiring to be touched. At the same time she was very sensitive to small angles of helm. With 5° of helm the circle turned in was about the same size as that turned in by the *Thunderer* with the helm hard over.

It was inevitable that the ship would heel a good deal under the action of centrifugal force in turning in these small circles at a high speed, and this was the case. The heel of the ship, on the circle, being in each case what is given by calculation, assuming that the centre of lateral resistance occupies a similar position to the centre of lateral resistance in the *Thunderer*, as obtained by the experiments. On the circle corresponding with full speed, with the helm hard over, the ship heels $8\frac{3}{4}$°.

This large heel has certain disadvantages; but in estimating the value of the remarkable manœuvring power possessed by this ship, it must be remembered that, in action, the captain will always be able to turn his ship with as little heel as he pleases,

* Strictly speaking, the track, after the helmsman has eased his helm, will not be the same over the latter part of the half turn as if the ship had continued to turn through 180° under the influence of the full helm angle.

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and that, at lower speeds, with the rudder hard over, the ship will turn in practically the same space as given by No. 3 experiment (Table II.), while the angle of heel will be considerably reduced; thus at 10 knots the heel would be 2°, and at 5 knots it would be ¾°, and at these speeds the ship could reverse her course in 2 min. 27 sec. and 4 min. 49 sec. respectively.

DISCUSSION.

Vice-Admiral P. H. COLOMB (Associate): Sir John Hay, and Gentlemen, I think this is the boldest attempt, at any rate it is an attempt on the largest scale, that has ever been made, to employ the cutting away of the deadwood to facilitate the manœuvring power of the ship. My attention was first directed to the possibility of improving the manœuvring power by cutting away the deadwood by the facts disclosed by the examination of a great number of the old trials, the old and rough measurements of ships' turning powers at the Admiralty; and I found that, amongst the various elements that go to make up the turning power, that influence it, the fact was, that excess of draught by the stern was, next to the helm angle, the one which showed itself most clearly. It seemed very natural that that should be so, because the resistance to turning must be abaft the pivoting point, and the greater part of it abaft the centre of gravity. I wish Mr. Watts, who is the father of the method of accurately measuring the turning powers of ships (although, unknown to him, similar methods a little time before had been used in France), had given us more details, and a fuller analysis of the curve, than we have been able to get from the paper and the drawing. But there is one thing quite certain, that he has got most extraordinary turning powers out of the ship. With regard to some of the best turning ships that I know (I am speaking from memory, and memory is treacherous), I think that four lengths of the ship is a very good tactical diameter. If you get a ship to reverse her course with only four lengths between the original and the reverse course, you have got a very handy ship, but here we have got a ship which apparently does that in about two lengths. That is a most extraordinary jump, and because it is so extraordinary a jump I should rather have wished to have had fuller details, and a fuller analysis of all that takes place; because, as we all know, there are a great many elements that go to influence the turning power of a ship in terms of her length, say; and I should have liked to have known, for instance, what the area cut away was, where the centre of gravity of that area lies, and I should like to have known more accurately what the area of the rudder was in comparison with the immersed middle line plane, in order to have got some idea of where we really stood with regard to the turning powers of this ship, in comparison with others that we know of. Mr. Watts takes the pivoting point as if it were a fixed point throughout the curve. Now, I have made a great number of experiments, getting out the curves, and tracing them, but unfortunately, my mathematical capacity is not great enough to have dealt with them as Mr. Watts would have dealt with them, but I am very strongly under the impression that the pivoting point is not a fixed point in the ship until she reaches the circular part of her turn; that is, until all the forces are balanced. From the moment you put the helm over, and start the rotary motion in the ship, she is henceforth seeking a balance of all the forces, the turning force of the rudder, and also the conversion of the moments of inertia into moments of momentum. Still, speaking from memory, my impression is that, in most of the ships I tried, I found the pivoting point passed forward, and in cases at first beyond the stem, further forward, out of the ship altogether, and then passed gradually

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inwards as the ship got on to the circular part of her turn, when it, for the first time, became a fixed point. I see Mr. Watts says he does not think that this ship got on to the circular turn angle—that is, the circular path—that the forces were not all balanced until after she had turned 360°. My impression is that most ships reach a practically circular arc when they have turned 90°, *i.e.*, 8 points. That appears to me to be the law which governs the turn, and that a ship which, roughly, shows a very small tactical diameter is longer in reaching that circular path than a ship which shows a larger tactical diameter. One of the things that is most important, to my mind, is the form of the curve. Every ship, as far as I know, has her own form of curve, and that form is not altered by the amount of helm. The whole curve is larger, but the proportion between the co-ordinates is the same at different points in the curve, whether the helm angle be large or small. There must be, I think, a very great reduction of speed. I do not think, as far as I know, that you can get a reduction of space unless you get a reduction of speed. I notice that the times of turning given in the table, with the low and the high helm angles, do not vary so very much for the turn of 180°, and that is what I have generally found myself; but, from the practical point of view, it is always important not to have the speed too much reduced when the turn is complete. I might perhaps mention (because I speak to you more from a practical side than a theoretical one) that, in ordinary fleet manœuvring, for instance, the manœuvring power does not come in so much. That was understood at the original formation of our system of manœuvring, and the manœuvring arc, as it is commonly called, is such an arc as would allow the longest and the worst turning ships a considerable margin. It is found that, with regard to fleet manœuvring, time is more important than space, and that to preserve the speed, and not to have variations in speed, is more important still. Therefore the great improvement made in the turning powers in that way does not come in. But, then, for fleet manœuvring it is necessary in your plan—and it is the plan in our fleet—that the turning powers of two ships are practically never opposed to one another. It is against the principle of the whole system of ship manœuvring that they should be; but it will happen, of course (we know it has happened), that sometimes that basis is not taken sufficient notice of, and ships are put into competition with one another, and then it is that the power given by this system comes in to avoid disaster. There is another point. That turn, which I always call the single turn—and we do not care much to investigate for practical purposes beyond the turn of 180°—but calling that the single turn, a very important matter to be considered is the effect of the double turn. What you do in the single turn has to be considered in relation to how it affects the double turn. Just supposing you put the helm hard over and turn 45°, when you have done that you reverse the helm to the same angle the other way, and then you want the time and the space, the trace of the path that you made from the point you started at, until you have resumed your old course. Generally speaking, I have observed that the time and the space in the double turn occupy three times as much as the original turn; that is to say, whatever space, whatever advance and transfer be made in the first turn of 45°, and whatever time it may take, it will take you three times that space, and three times that time, before you recover the original course. I think you will see, in the case of avoiding collision for ordinary sea work, apart from men-o'-war work, not only do you require (and it is a great element of safety to have) the powers of turning in very small spaces which are given to us in the *Yashima*, but it is also of great importance that we should not lengthen, in time or space, the double turn; because, in ordinary work, in moving ships at sea, it is not at all uncommon to put your helm the wrong way first under a wrong impression, and then you have to use the opposite helm to correct it. Now, if there is a great deal of time and space lost in that way, of course you have much greater danger than you have if it is otherwise, and I should like to have had from Mr. Watts some notion of how the cutting away of the

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deadwood affected that point. With reference to the rudder, there is a point also. In the experiments which I carried out for the Admiralty on this question of cutting away deadwood—although they were only carried out in a steam pinnace they were very full and complete—the deadwood was gradually cut away. I think there were three cuts, and every cut improved the turning powers both in time and space when the original rudder was left in its place. But, after all the deadwood had been cut away that could be cut away, the boat's turning powers with the old rudder were measured. Then a new rudder, of precisely the same area, only that the area was in width instead of in depth, was fitted, and we lost practically the whole of what we had gained in cutting away deadwood. I should like to have known something as to the area of the rudder, and as to its form, in helping to effect that very remarkable turn. I notice, what I should not have expected, that the ship appears to have great capacity for steering on a straight course. It is a very fine expression to say that a ship proceeding on a straight course is in unstable equilibrium, and I should have thought the cutting away of the deadwood—I do not recollect ever trying the experiment—would have made the ship somewhat more unstable; but from what Mr. Watts tells us, if he has sufficiently good proof of it, it is a very remarkable feature. The heel must depend a good deal upon the vertical position of the weights in the ship, the position of the centre of gravity, and so on; but it is, as Mr. Watts has properly said, no doubt an objection, and I think the method suggested for getting rid of that objectionable heel would increase the space required to turn a ship in, which is sometimes the most important point of all. It always seems to me in regard to the turning powers of vessels, like most other things, you cannot have your cake and eat it too; that, if you determine to have very remarkable turning power in space in that way, you must give up something for it, and the heeling is perhaps one of the inconvenient things that cannot be got rid of. In the same way, the reduction of speed at the conclusion of the curve, which is a very distinct objection on many grounds, I think you cannot help either. When you turn in a very small space like that, you must take away from the propulsive power a very large quantity and put it into turning power, and you cannot expect to have your cake and eat it too in that way. I think that is all I need say.

Mr. J. Macfarlane Gray (Member of Council): I congratulate Mr. Watts upon the success attained by his cutting away the deadwood. There is certainly in these trials a very remarkable advance in speed of turning and in reduction of steering circle since I witnessed the first steam turning experiments in 1868 with H.M.S. *Northumberland* off the Isle of Wight. I have always regarded the steering of a steamship as the same in principle as the steering of a wheelbarrow; the rudder in the one case, or the man between the handles in the other, moves sideways to produce the turning. If, therefore, a vessel were on a course parallel to a straight breakwater when the steering circle commences, I think the stern would, to some extent at first, approach the breakwater. According to the diagram on Plate LII. there would be no approaching, the motion would be wholly away from the breakwater. Perhaps a dotted line could be added to show the space within which the vessel does actually move.

Sir Edward Reed, K.C.B., F.R.S., Vice-President: Sir John Hay and Gentlemen, I have very little to say about this paper, but I should like to say that we may consider ourselves fortunate, I think, in receiving to-night from Mr. Watts a partial statement as to the results of his improvements, and also some remarks from Admiral Colomb, whose systematic experiments in turning of ships were the first, and probably the most important, that have ever been made. I think it is a great advantage to have had him here to-night to make the very pointed and instructive speech he has delivered. I say this paper gives but a partial account, for the reason that it is obvious that a statement of the

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performances of one of Mr. Watts' ships under steam, and under the helm, would admit of very large development over and above that which we have heard from him to-night. I do not myself altogether admire, nor do I entirely concur with, the wheelbarrow illustration of Mr. Macfarlane Gray. I did not think it was necessary either; because, it seems to me it must be obvious to everyone that, if you put a rudder at one end of the ship, and put that over to receive a large impression of power upon it, the first and most natural effect of that is to drive the stern of the ship round. I think it would puzzle anybody to apply that large transverse force, or partly transverse force, to the stern of the vessel, whether she is moving ahead or whether she is receding, without producing that result. It seems to me that is the most obvious consequence of applying rudder power. One thing, I think, comes out very strongly in these experiments which Mr. Watts has so kindly given to us, and in all experiments bearing upon turning, and that is, the enormous advantage which you get in the application of turning power by the instrumentality of a rudder in preference to any other mode of applying it. I remember very well about a thousand years ago, or fifty, or thirty, or forty, or something of that kind—I think about fifty would be nearer the mark—a screw propeller being fitted in the deadwood of an old man-of-war at Sheerness Dockyard. I think it was suggested by the Earl of Dundonald—I do not know—but it was put with its axis transversely to the ship, so that the whole power of the screw was put to bodily forcing the stern of the ship round, and the amount of steering power that you got by the force thus alone capable of being applied to it was very slight indeed, and brought to my youthful mind at that time a strong impression of the value of the rudder. Now, Sir John Hay, I should not have risen were it not to make an appeal to the officers and members of this Institution, to Mr. Watts, and to Sir William White, if he had been here, for the purpose of getting a more complete development of steering trials in connection with these modern ships of large power, and of cut-away deadwoods. I do not think it is at all possible to exaggerate the steering value of what has been done in Mr. Watts's ships. I have had the privilege of being associated with him in the production of recent large vessels of war, and I have very gladly myself accepted his improvements in that respect, and all the vessels in which I have been jointly associated with him have this feature. Now it is very difficult for even Mr. Watts, with the large and commanding opportunities of the Armstrong Company, to perform enough experiments for the purposes of science in this respect, and it is very difficult, because every trial that they make, or most of the trials which they have to make, have to be made in the presence of, and more or less in the official view of other gentlemen, principally officers of foreign governments, and it is only natural, when you look at the enormous expense of steam trials, that they should get through those trials which are essential to the successful passing of the ship, and to the obtaining of the necessary certificates, as speedily as possible, rather than that they should proceed for hours, and perhaps days, to perform scientific experiments with the splendid but costly instruments which they have in their hands; but I think, with all the resources of the British Government—and the Admiralty deserve great credit for having recently multiplied steam and other trials very largely—I think we might look to the Admiralty to give us, not only one, but perhaps more than one example of exhaustive steering trials. I think the Admiralty should do this, not only in the interests of this Institution, and of science, but in the interests of the public service. Not very long ago, having to be present at the trials of a large and important vessel—not a fighting ship—we had the advantage of the presence of a distinguished naval officer, who had had almost as much experience as yourself, sir, and as much as, or perhaps more than, any naval architect in the room, and he had a very strong and firm opinion as to the proper manner of using the twin screws and the rudder in relation to each other, in order to effect the most rapid turning operations. Our steam trials fortunately went off very smoothly and comfortably, and we had a little

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time left for playing, and so we brought the opinions of this officer to a test, and we made some experiments extending over some hours for the purpose, and we found his view was entirely wrong; that the effect of using the twin screws in the manner he proposed, produced the very opposite result to that which he had anticipated. He was a very capable and experienced officer, and I confess, for myself—I do not now, and never did, speak with much confidence—that I did not venture, on that occasion, to say positively what would be the precise result of the experiments we made. Now, I think if it were possible for so experienced an officer to make a mistake touching the manœuvring of a twin-screw ship, it is quite possible for those younger officers, who are coming now so largely into the command of twin-screw vessels of war of great speed, to make mistakes, and not to be acquainted with all the facts and circumstances of vessels steaming at high speed, and the relative use of the screws and the rudder, and I think the Admiralty ought to put this question at rest, and to give us exhaustive and authoritative information on this subject for the benefit of the Naval Service. No doubt other naval services would benefit by it, but we never, fortunately—and perhaps in this Institution less than anywhere—seek to restrict the expansion of our information because of the fear of its falling into the hands of those who might, under conceivable circumstances, profit by it to our disadvantage. I think that is a secondary consideration. I do not see any high Admiralty officer here to-night, but I do hope the suggestion I have made will reach the Admiralty, and Sir William White in particular, who naturally would have very great weight in a matter of this kind, and that he will take it into consideration, and that we shall have an opportunity of having placed before this Institution large and complete results of turning trials in ships of two or three different sizes and types. I can only say I hope amongst them will be ships with the deadwood as completely cut away as Mr. Watts habituates himself to removing it; because I am quite sure, in that respect, that the advantage is very great indeed. I am rather in a difficulty on one point of detail. Admiral Colomb made it clear that he had so read the paper of Mr. Watts as to understand that he had assumed a sort of fixed point as the pivoting point of a ship under certain conditions, and then the Admiral pointed out that sometimes the pivoting point was, according to his experience, not only not fixed, but was not in the ship at all. I did not quite read that point into Mr. Watts's paper—he will have an opportunity of speaking upon it—but the very fact that such a point as that should be in doubt in the discussion here, shows, I think, that I am quite justified in asking, in the first place, Mr. Watts to use the best opportunity he has to give us a fuller paper on this question, with fuller facts, and capable of having more inferences drawn from it, and also in asking the Admiralty to let us have fuller results of experiments.

Mr. S. W. Barnaby (Member of Council): Sir John Hay and Gentlemen, I am sure Mr. Watts is to be very much congratulated on having succeeded in getting such wonderful steering power in a vessel of this size. This large ship steers like a turn-about boat used to do. As to the instability of a vessel steering upon a straight course, I think it depends on this: as soon as the vessel inclines in the least degree from the straight course, the pressure of the water upon the bow is in excess of the pressure upon any other part of the surface, and therefore tends to drive the bow further round in the direction in which it is already moving. I take it, in a paddle vessel this is more apparent than in a screw vessel, because the screws tend to resist any motion of the stern, having a decided objection to being moved sideways. The cutting away of the deadwood (although I think it must tend to make the ship less stable upon a straight course) does not seem to be seriously detrimental. Then, as regards the angle of heel which a ship takes under helm, I think Admiral Colomb is probably right when he says that you must expect a heel with a big ship of this sort, and it would

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probably be in every case in a large ship—a heel outwards. This is described as due to centrifugal force. In a small vessel, like the destroyer, you can force the ship to heel inwards when you put the helm over. That is because the centre of pressure of the rudder is below the centre of lateral resistance of the vessel, and she heels towards the centre round which she is turning, and it is only on straightening the helm you get a slight heel outwards. The steering capabilities of this ship appear to reflect credit not only upon the designer of the ship, but, I should say, also upon the maker of the steering engine (I do not know who he is), because to put a broad rudder like that over in a battleship in eight seconds seems to me to be a somewhat remarkable performance.

Mr. PHILIP WATTS (Member of Council): With regard to Admiral Colomb's remarks, the trials and observations might well have been more extended, especially as it was apparent to all, from the first, that the performance was very remarkable. The area and shape of the rudder, and the extent to which the deadwood is cut away, are shown on the profile of the after part, and I shall be glad to add the other particulars asked for. I think the pivoting point moves forward immediately after the helm is put over, but it very soon becomes practically a fixed point. After turning through 180°, for instance, it may certainly be regarded as having reached its final position. I think Admiral Colomb is probably right in supposing the final circle is practically reached very early in such ships. He has made a very great number of experiments, and he is entitled to speak with a great deal of authority on this point, and also on the other interesting points to which he referred. I do not think the cutting away of the deadwood has any special influence on the time and space required for the *double turn*, except in so far as it reduces the diameter of the circle turned in, and enables the ship to answer her helm more quickly. Admiral Colomb spoke of the advantage of being able to turn quickly in connection with avoiding collision, but he did not refer to the advantage possessed by a ship having great turning power in being able to avoid being rammed, and being enabled to ram another vessel, which is, beyond question, a very great advantage. It will be seen from the profile that the rudder extends in depth to very nearly the line of the keel, and it is probably as wide as it could be made with efficiency. With regard to the effect of the removal of the deadwood on the slightness of the tendency of the vessel to deviate from a straight course with the rudder amidship, I think the very large rudder area practically compensates for the removal of the deadwood. I can add the curve asked for by Mr. Macfarlane Gray, showing the space required by the stern in turning. I think that was your point, Mr. Gray?

Mr. MACFARLANE GRAY: Yes.

Mr. WATTS: With regard to Sir Edward Reed's remarks, one object I had in view in reading my paper was to draw attention to the necessity for experimental investigation for ascertaining the turning qualities possessed by various forms of ships. There are many facts in connection with the steering of ships which indicate that our knowledge on the subject is at present very incomplete. Admiral Colomb put this with a great deal of force when he remarked, "Every ship has her own form of curve." Our present knowledge does not enable us to say beforehand what will be the nature of the curve in which a ship of new form will turn. As Sir Edward Reed pointed out, it is difficult to make complete experiments with accurate observations on the turning of ships, and in the ordinary completion trials there is scarcely time or opportunity for doing this. Moreover, in order to deal with the whole problem, such a large number of forms would require to be examined that I think it hopeless to expect to arrive at satisfactory results from experiments with actual ships; and I have, therefore, come to the conclusion that the subject can best be investigated with models. I hope to be

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able to do something in this direction myself, but I trust that others who have the opportunity will also give their attention to it. Mr. Sydney Barnaby referred to the heeling. Of course, the effect of the pressure of the water on the rudder tends to make the ship heel inwards in all cases, and the *Yashima* first of all heels inwards when the rudder is put over, and then, when she begins to turn, she gradually rights herself, and then begins to heel outwards. When she has fairly commenced to turn, the couple due to centrifugal force—whose moment is the centrifugal force multiplied by the distance between the centre of gravity and the centre of lateral resistance—which tends to make her heel outwards, is very much greater than the couple whose moment is the transverse pressure on the rudder multiplied by the distance between the centre of pressure of the rudder and the ship's centre of lateral resistance, which tends to make her heel inwards.

Mr. S. W. BARNABY: The destroyers keep an inward heel right through the curve.

Mr. WATTS: Quite so; that is because the centre of lateral resistance and the centre of gravity are near together in these shallow draught vessels, while the rudders are very low down, and, consequently, the couple due to the transverse pressure on the rudder is greater than the couple due to centrifugal force. Mr. Barnaby also referred to the steering gear. This gear was made by Messrs. Harfield & Co. The rudder can be put hard over from amidships in eight seconds, and I think it can be put over from one side to the other in about thirteen seconds. The force, however, required to put the rudder over is not very great, because the rudder is almost exactly balanced. I am very much obliged to you, gentlemen, for listening to my paper.

The CHAIRMAN (Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I am sure the meeting is very grateful to Mr. Watts for a paper which has led to such an interesting discussion. We have to thank him also for the clear explanation which he has given of the various questions which have been asked him, as well as for the promise to add the further explanations to his paper which have been asked for. I can express the thanks of the meeting to him, I am sure, with your full consent.

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SUBMARINE TORPEDO-BOATS: THEIR INFLUENCE ON TORPEDO-BOAT ARCHITECTURE AND VALUE IN WARFARE.

(Illustrated during the reading by 120 Lantern Views.)

By Captain WILLIAM H. JAQUES, Associate.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, April 1, 1898; Admiral the Right Hon. Sir JOHN DALRYMPLE-HAY, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

ALTHOUGH actual warfare may be the only *definite* means of establishing the value of new developments in naval architecture, it is too expensive a method to depend upon, and the awaiting of its solution would subject us to the enormous disadvantage of want of preparation and proper insurance which demand an earlier decision upon the questions involved.

Fortunately, the peace and prosperity of the great nations have not been disturbed frequently enough by war to secure their dictum that the generally accepted type of torpedo boats is one which has *not* come to stay; but there is evidence enough in the results that obtained in the late Japan-China war; in the discomfort of life on board; in the accidents incident to manœuvring; their unfitness for serious work at sea; the great fatigue to which the crews are subjected; and the marked strides in torpedo-boat construction to reach speed, protection, and a reasonable defensive power, to convince us that the present torpedo craft, whether she be carried on a battleship, or is a torpedo-boat destroyer, is neither *sufficiently protected* nor *invisible*, nor can she keep the seas without ruining her *personnel* or meeting destruction.

The torpedo-boat experience gained in the Japan-China war especially demonstrated the fact that the ordinary torpedo-boat had more defects than enduring or reliable qualities, and there is abundant evidence, certainly, to *suggest*, if not *convince*, that there must be some radical change in the present torpedo-boat architecture.

The desire, or attempt, to produce a submarine boat for war purposes is not by any means new, nor have the controlling elements of design been restricted to one principle, except in the Holland system with which Mr. John P. Holland has for so many years been directly associated.

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It must not be forgotten that some of the essential and most widely acccepted principles of the present battleship were taken from the American monitor, a type that for many years was practically discarded, but which during the United States Civil War in the crisis of 1861 accidentally, but completely, gained such a decisive and remarkable victory as not only to largely influence the course and conclusion of the Civil War, but to impose conditions on subsequent naval architecture that have been universally accepted. And this victory was gained directly in the face of the most intense opposition of naval officials. If the late monitor had not had the opportunity of war to prove her value, it is extremely doubtful if she would ever have had such an important place in naval history or naval architecture.

All treatises on torpedo-boats, all reports in connection with their construction and supply, all references to their achievements, emphasise, more or less, the requisite of *invisibility* and power to reach an enemy, and to successfully get torpedoes into an enemy's ship.

The development of the submarine-boat, its power to disappear, its ability to move quickly, its valuable element of submergence, the practicability of protecting by armour its limited visible portion, and the surety of its fish-like qualities, must have a radical influence in modifying the present types of torpedo craft, no matter whether it replaces the second-class torpedo-boat on board a battleship, whether it is employed for submarine purposes pure and simple, or, as most probably will be the case, whether its submarine principles are utilised to protect the semi-submerged torpedo-boat and to meet the practical conditions sought for in combining such invisible and protective qualities as will enable the torpedo-boat to surely get in her work.

A few moments can be instructively given to the value of mine and torpedo explosives and the effect of internal explosion. I will give you three practical examples, and graphically illustrate them. They are :—

I. Experiments made at the United States Torpedo Station, Newport, R.I., to determine the effect of submarine explosion on animals placed in a submerged tank.

II. The recent destruction of the battleship *Maine*.

III. The 12 in. gun explosion in the turret of the Russian armour-clad *Cissoi-Veliki*.

[In connection with the Newport experiments, Captain Jaques presented eighteen views, showing the arrangements for the experiments, the vessel in which the animals were confined, the explosions in order, the effects of the explosions on the torpedo shell and its condition.]

Eighty-one pounds of gun-cotton were used; the first attack was at a distance of 431 ft., the subsequent distance decreasing until the last, which was 80 ft. The

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submergence in each case was the same for both mine and boat—15 ft.; and in no case was the attack made directly from underneath. Rabbits, pigeons, chicken-cocks, and a cat were the animals used: they were entirely unhurt, and the vessel itself was practically uninjured.

[To illustrate the destruction of the U.S. battleship *Maine*, ten views were presented, showing details of the explosion, its terrific character, where the greatest havoc was done, the keel plates blown above the surface, and a diagram of the estimated course of the explosion. These were supplemented by four views showing the disastrous effect of the rupture of a 12 in. gun in the Russian armour-clad.]

Of the misfortunes that have come to nearly all nations by the loss of their warships, I can recall no other which, in its results, has given as great emphasis to the possibilities of torpedo success as the recent destruction of the battleship *Maine.*

From the torpedoist's point of view the failure to locate the responsibility is a tribute to the value of the invisible character of the cause. If there had been a submarine torpedo-boat in Cuban waters at the time, no doubt history would place the responsibility upon it.

The literature of the early history of submarine navigation is, more or less, familiar to you all, and, while nearly all the experimental boats, even those of the seventeenth century, have thrown some light on the subject, the *Plongeur*, the Nordenfeldt boats, those of the Goubet and Alexandrofsky type, the *Gustave Zédé* and the *Holland* have received the most prominence and attention.

Bushnell's boat (1771) was controlled by hand and lead ballast. Phillips in 1851 employed, in a craft built for a family yacht, compressed air, submerging tanks, and hand propulsion; but later he designed a boat for war purposes in which steam was to be employed. The submarine boat that destroyed the *Housatonic* during the United States Civil War employed manual power, but it is generally believed this fatal attack was not made as a submerged boat, but by the methods usually employed by spar-torpedo boats. In 1863 commenced the experiments of Admiral Bourgeois and Engineer Brun with *Le Plongeur*, in which compressed air was specially employed. Dr. Barbour in 1869 suggested many complicated devices. The *Intelligent Whale* (1870) was propelled by hand, employed compressed air for respiration, and water tanks for submergence. In the Tuck boat, water tanks, compressed air, electric accumulators and motors, and electro-magnets were tried. She was named the *Peacemaker*. In 1875 Mr. Holland presented a plan for a boat to be operated by a single individual. From 1881 to 1883 much prominence was given in France to the boats built by M. Goubet, in which he employed compressed air and electric accumulators. In 1886 and subsequently, many interesting tests of Nordenfeldt's boats were made, and I had the pleasure

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of being present in Southampton Water to witness what the Barrow boat accomplished. In Spain the *Peral* has been looked upon with much favour.

[Twenty-three views were thrown upon the screen to illustrate these various types.]

All sorts of mechanical contrivances and powers—compressed air, electricity, petroleum, and reservoired heat—have been separately or collectively employed in them. It is by a careful study of what has been done in these types, and of what has caused their failures, added to the benefits and advantages which industrial development has provided in mechanics, metallurgy, and electricity, that we are able to present to-day a craft built on the vital Holland principles, which we believe will be, not only of great value to naval architecture, but of great usefulness in war, and which will have a powerful influence in the removal or reduction of the defects of the present torpedo-boat.

Before describing the two submarine boats, the *Plunger* and the *Holland*, now receiving so much attention in the United States, let me say a few words about the four boats built under Mr. Holland's direction, and in and with which he made the experiments that rendered his final success possible.

The first one was built in 1877 by the Albany City Iron Works of New York. Her dimensions were 14 ft. 6 in. long, 3 ft. beam, and 2½ ft. depth; she had a double body, the inner one being cylindrical; water space between them. She was operated by a 4 H.P. petroleum engine with one screw, and had vertical and horizontal rudders.

Mr. Holland experimented with this boat for nine months, and, although her petroleum engines were a failure, and the speed was very unsatisfactory, he proved that he could submerge her at will and keep her under water, and determined that the horizontal rudders were useless when placed in the transverse axis, but effective when at the stern.

After he demonstrated that it was possible to control the boat under water, he had the engines pulled out, and sank it under the Fall's Bridge at Paterson, N.J., where the hull now lies in the Passaic river.

Boat No. 2 was commenced in 1879 at the Delamater Iron Works, New York City. She was finished and delivered to Mr. Holland in April, 1881; he started experimenting with her immediately, and continued until October of that year. In that boat he made most of his experiments. She was 31 ft. long, 6 ft. in diameter, 19 tons displacement, and was fitted with a 15 H.P. Brayton petroleum engine. With a crew of one engineer and himself he cruised all over the harbour of the North River. Most of his experiments were made under water. As an example of the perfect control of pressure, Mr. Holland relates that, with the boat submerged and resting on a gravel bottom, the

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engineer opened a bottom manhole, stepped out (without a diving suit), lifted the hull slightly with his hands, and then got in again and closed the manhole.

With her armament of a submarine gun 10½ ft. long and 9 in. bore, he succeeded in getting a perfectly straight projectile trajectory under water for about 40 yards. To fire the submarine projectile he used 200 lbs. air pressure; the highest was 495 lbs., but it did not appear to make much difference in the range; 250 lbs. did nearly as well. The Delamaters built the projectile. This particular pneumatic gun was made of a welded steel tube, and was the foundation for the pneumatic gun system that was afterwards developed under the management of the Pneumatic Dynamite Gun Company. This craft is now lying at New Haven, Connecticut. Her engine is still in her, but the air compressor was taken out about two years ago to run a forge.

Boat No. 3 was built at Gannon's Copper Shop, Jersey City, New Jersey, and was a working model. In her Mr. Holland first employed the apparatus for steering under water in the horizontal plane; he intended to build a gunpowder engine to propel her under water, but, before he accomplished this, she was sunk opposite Whitestone, the engineers, not understanding how to fasten the turret, having left it open about half an inch. A few experiments under water were made before the accident. She was 16 ft. 4 in. in length by 28 in. diameter, and of one ton displacement.

Model No. 4 was known as the Zalinski boat, and was built at Fort Lafayette, of composite iron frame, planked with wood; she was 40 ft. long, 8 ft. diameter, and it was the intention to arm her with large Zalinski pneumatic guns. The launch was mismanaged, the ways broke under her, she fell on the rocks, and was seriously damaged. She was repaired sufficiently to carry on experiments at the dock, where she was frequently submerged, and much information secured concerning the control of water ballast. She was finally broken up.

In all these boats Mr. Holland's fundamental principle was to dive, and not to *control* them, as in the foreign types, either by the inlet, or outlet, of water, or by down-haul screws alone.

The main things proved by these experiments were: that in submarine boats it was essential to have an unmovable centre of gravity; that the movable centre was the cause of nearly all the failures; that during the submarine run the weight must remain absolutely unchanged, being kept the same automatically, otherwise she cannot dive when you desire it, or she may run to too great a depth.

Another thing demonstrated was the value of a boat that would be as small as possible, consistently with having sufficient offensive power. It must also be quick-acting, so as to be able to come to the surface and to disappear as rapidly as a porpoise. A cardinal principle governing its design is simplicity.

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While there have always been naval officers in the United States who have advocated the value of submarine boats, and the Navy Department has at various periods interested itself in them, the advertisements of November 26, 1887, and May 1, 1893, called forth the most important proposals, and a contract was entered into with the Holland Company in 1895.

The one constructed by the Holland Company for the United States Navy Department was named the *Plunger* by the Department, and was launched August 7 of last year at the constructor's yard in Baltimore. She is the fifth one designed by Mr. Holland, and is 84 ft. long, of circular section, 11 ft. 6 in. diameter, surface displacement 149 tons, submerged displacement 165 tons, with a reserve buoyancy of about a quarter of a ton. The guaranteed speed is 15 knots on the surface and 14 knots, with her steam machinery, for a period of 12 hours while awash, with 1 ft. of the turret above the water. Her totally submerged electrically running speed must be 8 knots for six hours.

There is a turret amidship with four inches of protection and a superstructure for a fair water. Two down-haul screws have been added, although they are not considered by Mr. Holland a requisite of the system. There are two openings in the nose-piece through which service torpedoes are to be discharged.

In addition to hand-gear for horizontal steering and diving, there are automatic devices for maintaining submergence at predetermined depths. A camera lucida has also been fitted.

The hull has been constructed to admit a submergence of 75 ft. Some of the water-tight compartments serve as water-tanks; others contain oil fuel; others are employed for compensating discharged weights. A special device compensates for the oil consumed. There are four rudders, two for steering horizontally and two vertically, controlled by automatic devices.

For running on the surface or awash, steam generated by petroleum is employed, while electricity from storage batteries is used under water. There is one water-tube boiler of the Mosher type of 3,000 sq. ft. heating surface, fitted with a system of oil fuel capable of consuming 2,000 lbs. of oil per hour. There are two main, vertical, triple-expansion steam-engines of 600 H.P. each, and one auxiliary of the same type of 300 H.P.

The electric machinery is composed of one main motor of 70 H.P. for propelling the boat when submerged, operating either the side or centre shaft, or used as a dynamo for recharging batteries. There are additional electric motors for operating down-haul screws and performing other services as required.

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Air for tank and ventilation service is supplied from commercial reservoirs. There are special fittings for closing smoke pipe and air ducts quickly before submerging, and the tank operations are very simply controlled by Kingston and compressed air reducing valves.

The liquid fuel system installed in the *Plunger* is similar to that which has been successfully operated in the United States torpedo-boat *Stiletto*, and which will also be placed in two of the last boats recently completed for the United States.

In practice with the *Stiletto* the system was found to give no trouble from carbonisation, or the deposit of particles of carbon in the burners.

The *Plunger* has three propellers (in addition to the down-haul screws), any one, or all of which can be operated by either steam or electrical machinery.

Owing to the delays incidental to the many modifications of the *Plunger*, constructed for the Navy Department at the Baltimore shipyard, the Holland Torpedo Boat Company decided to build a boat into which the essential elements of Mr. Holland's type could be introduced and experimented with by the company, and boat No. 6, the *Holland*, was built at the Crescent Shipyard, Elizabethport, New Jersey, by Mr. Lewis Nixon. Its form resembles that of the porpoise (Plate LIII.), and its dimensions are :—

Length	53⅓ ft.
Diameter, amidships	10¼ ,,
Displacement, light	64 tons.
,, with superstructure awash	74·2 ,,
,, submerged	74·4 ,,
Reserve buoyancy...	0·2 ,,

In this boat no attempt was made to secure a higher speed than was necessary to secure proper diving and steering properties. It was fitted with a 50 H.P. gasoline engine for surface runs, air compression and storage battery charging, and a 50 H.P. electric motor for submerged work.

Its armament consists of one 18 in. service torpedo tube and two dynamite guns fitted for powder and compressed air discharge. From four to six men are required for her operation.

At a speed of 8 knots the *Holland* manœuvres, steers, and dives beautifully, and the control of submergence is speedy and easy. Her stability has been thoroughly proved, and the atmospheric conditions when submerged are infinitely safer and more comfortable than those of the ordinary torpedo-boat.

Comfort is comparative; we have not yet been able to provide such luxuries of art, observation, and cuisine, as those installed in the *Nautilus* by Jules Verne's

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imagination, but we can place our machinery for operation quite as conveniently as that, in the modern torpedo-boat, if not more so.

The recent experiments with the *Holland* [the model of which was placed on the table] were most simple, their very simplicity no doubt suggesting the many interesting and lengthy reports which have been published in various journals. The trials consisted chiefly in surface runs, submergence for the adjustment of ballast and test of Kingston and air valves, adjustment of the registering apparatus, and finally diving.

Although some surprise has been evinced that several days were required for ballast adjustment and the test of the air and water valves, we think nothing of leaving our clock or watch at the maker's for a month, or more, to have it properly adjusted, nor do we wonder at the length of time required to adjust the depth mechanism of the Whitehead torpedo for its automobile work, and yet neither of these have living men in them to be cared for.

Of these successful experiments one writer has said :—

Those mariners and naval architects who long were loud in expressions of scepticism concerning the submarine torpedo-boat *Holland* are to-day less vociferous when they are not silent. Demonstrated facts are pretty good things on which to build an argument and appeal for a verdict, and, as far as it has gone, this new type of naval terror looks as if it were about to establish a new basis of calculation in international disputes.

Mr. Nixon, her builder, says :—

The *Holland* is a success, and she is now prepared to take her place as a recognised factor in naval warfare, and an element that must be considered by all navies from this time on.

These boats are fishes, able to exercise all the functions of a fish, with the brain of a man, and the destructive power of a man-of-war.

Of the *Plunger*, Chief Constructor Hichborn, of the United States Navy, has said :—

Even should this vessel be not a perfect success, she may mean to future fighting ships and methods of naval warfare what the much-doubted monitor has proved to our present navy.

Although the Holland Company has several designs, simple and novel, for the armament of submarine boats, in the presentation of this paper it is not intended to ask your consideration of them; for the boats themselves can be readily fitted with Whitehead or Howell torpedoes, employing powder or compressed air discharge, or with over-water projectiles fired with either powder or air or a combination of both.

If these vessels are to be supplied in large numbers; if they are to be quickly built and to become speedily available for the crises which arrive to every nation, their advantages can be the more readily understood when it is known that the elements of which they are composed and built are commercial products. Gas and steam engines

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can be secured from a hundred builders; electric motors have replaced and are as easily procurable as horses; electric storage batteries, although still far from being fully satisfactory, are no longer novel and difficult to obtain; compressed air cylinders are increasing every day in strength and capacity, liquid air is no longer a toy in the laboratory, and, thanks to Professor Roberts-Austen and others, we are now assured it will soon become an inexpensive commercial product; petroleum fuel can be carried with less danger than bituminous coal; and the parts which compose the special controlling mechanisms of the system are all marketable products, easily and quickly assembled and adjusted.

In conclusion, I desire to emphasise the fact that submarine navigation, which has so long been attempted by many nations, is at last an accomplished fact, and that we are not speaking simply from theory, but from actual practice and serious experience in a useful submarine boat, and that the advances in perfecting a submarine torpedo-boat are as great as those made in steam heating over the devices employed in the middle ages.

In the design and construction and practice with the Holland submarine boats *Plunger* and *Holland*, we have been going on the principle of developing not a boat simply as a toy or a working model, but one which will be especially useful for the primary purpose to which a submarine boat should be put—that is, of actually fighting vessels around the harbours and on the coast, instead of in the open sea.

The dimensions of a submarine boat proper should be governed by the necessary offensive power, and, while having in it all the destructive power desired, it should be small enough to get close up to and, practically, nibble at the bottom of the ship to be destroyed.

This object appears to have been accomplished in the *Holland;* for she has all the speed necessary to control her fish-like qualities, has power to disappear, can take care of herself, and, at the same time, is able to work three very powerful guns.

While this has been accomplished, no doubt other valuable developments will be in the direction of small craft to take the place of second-class torpedo-boats on battle-ships, and of semi-submerged boats of almost any dimensions, having armour enough above water to afford ample protection, at the same time protecting all the rest by water. (Plates LIV. and LV.)

We all know how difficult it is to adequately protect a ship with armour even by a most careful distribution of weights. The semi-submerged boat presents a type in which you can armour such parts as are necessary, employing very heavy armour because you have reduced to a minimum the part exposed, and possessing submarine

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qualities, it is the only kind of boat that will do this, as you well know there is not a torpedo-boat in existence to-day that will meet these conditions.

In such a craft you can get close up to your ship and fire the torpedo into her, while an ordinary torpedo-boat will be simply riddled and sawed into pieces by rapid-fire ammunition. Further, a semi-submerged, armoured torpedo-boat will be able to get so near her target that, by greatly reducing the range, she will eliminate many of the disadvantages of the present long ranges required for the Whitehead torpedo. Again, you are giving a well-disciplined crew a chance to do something, for their quarters will be infinitely more comfortable than those they at present occupy in the torpedo-boat; they will have a feeling of safety which they do not now enjoy, and they will know that they will land their torpedo close enough to blow up the ship. Such a craft may be compared with a large automobile torpedo, one of sufficient size to carry a crew and yet possessing, not only, similar automatic devices for controlling its position, but, having them supplemented with mechanical contrivances under the direct control of the brain of man.

Such a boat will be practically irresistible and invulnerable; will even resist the attack of heavy ordnance, and is a type that it will be impossible for a battleship to avoid.

While giving importance to the designs that will utilise the semi-submerged principles, the great need of the hour for harbour and coast defence is a small torpedo-boat that can be submerged, having within it a storage battery of sufficient power to give it a submerged range of a few hours, with nine or ten knots surface speed and from six to eight knots submerged. Such craft can be quickly and cheaply constructed, and very much more efficiently controlled and protected than the very rapid torpedo-boats or torpedo-boat destroyers which represent the magnificent mechanical development of the present age, so much of which has been accomplished under the direction of two distinguished Vice-Presidents of this Institution, Mr. Thornycroft and Mr. Yarrow.

You will perhaps say that very little has been accomplished in submarine navigation in proportion to the number of years during which the system has been under consideration and experiment; but, you must remember that the best commercially accepted torpedo—the Whitehead—has struggled through many years, is yet very far from being perfect, and directive power for it has only recently been secured by the introduction of the principle which was the controlling one of the Howell, that is, the gyroscope.

You must also recall that most torpedo destruction has been done with a bag of explosive on the end of a pole, and that the submarine boat will permit you to get closer to the enemy, with a bigger bag of explosive, and with less danger to the pole.

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If you compare, directly, the chance of the ordinary torpedo-boat with that of a submerged boat for landing a torpedo, there certainly can be very little doubt as to which is the more hazardous; and I sincerely trust that I have been able to present sufficient data to you of what has been accomplished to prove that, by the suggested modifications, you are getting all the advantages of attack, with almost absolute safety to the torpedo-boat itself.

If there are no other elements of value in the submarine boat than its influence in modifying the present type of torpedo-boat, this alone should certainly give it prominence and weight—a powerful influence which certainly cannot be ignored.

DISCUSSION.

Mr. A. F. Yarrow (Vice-President): Sir John Hay and Gentlemen, I think the Institution is under a very great obligation to Captain Jaques for the very interesting paper which he has given on a subject new to us. Captain Jaques has undertaken the voyage from America on purpose to present this paper to us, and I think it will be admitted that it has been one of the most interesting that we have had. I know nothing about submarine torpedo-boats, and do not propose, at my age, to go in for this departure in naval architecture. I have no observation to make, except that I think we have some security in Captain Jaques being connected with a venture of that kind. He is very well known in this country, and his energy is, I am sure, appreciated, and, as he has taken the subject up, I think we may now look forward to see some interesting developments in this direction.

Mr. S. W. Barnaby (Member of Council): Sir John Hay and Gentlemen, as Mr. Yarrow has said, Captain Jaques is very well known by name and reputation in this country, and especially as an authority on torpedo-boats; so that when he vouches for the success of this boat we may accept his statement. At the same time, I must say I think he has become a little of an enthusiast on the subject of submarine boats now, and he has painted them in rather rosy colours. For example, he talks of the absolute safety of the submarine boat. Well, I am afraid we do not all feel that absolute confidence in their safety, which would embolden us to venture ourselves in them. He also says that the comfort of the crew of the submarine boat, as compared with the comfort of the crew of a torpedo-boat, is very great. That seems to me a little hard to accept, because we do provide room in torpedo-boats for the men to get out on the deck and walk about, so as to obtain a little fresh air, but when the engineer wants to stretch his legs in a submarine boat, Captain Jaques tells us he has to get out through a manhole at the bottom, and to lift the boat on his shoulders and go about like a hermit-crab! It seems to me there must be great difficulty in finding your enemy in a submarine boat. Even in a torpedo-boat, where the deck is 5 or 6 ft. above the water, it is difficult to see anything at any distance. It is, of course, still greater in a boat awash, and when you go under the water you can see nothing. I have heard a naval officer describe the navigation of a submarine boat as like navigating in a fog on a lee shore—you cannot see where you are going, and the bottom is always your lee shore. The pneumatic gun I should have thought a little difficult to manipulate in a boat of this sort, because you have no constant direction at all; whereas, in a boat floating on the

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surface with considerable longitudinal stability, one only has to allow for sideways divergence. Still, at the same time, this boat has evidently done very well, and I think we may expect to find future development of the system in either plunging boats, or, at any rate, boats lying awash or near the surface, for certain purposes. I do not think the argument against torpedo-boats can be made to apply as Captain Jaques applies it against destroyers. The torpedo-boat has developed in the face of these disabilities which were recognised from the first. It has always been accepted that the torpedo-boat must attack her enemy either in the dark or in the smoke of action; nevertheless, she has found great favour. The destroyer does not attempt to destroy ironclads but torpedo-boats, and, it seems to me, her existence is justified by reasons which are not touched by the arguments, however much force you may give to them, against torpedo-boats.

Mr. B. Martell (Vice-President): Sir John Hay and Gentlemen, I have only a word to say. I should like to ask Captain Jaques whether any practical experiments have been made, such, for instance, as a hulk anchored out in some stream and one of the submarine boats going to attack her; and whether that has been successful, and she has blown up the vessel. It seems to me that would give us practical confidence in the success of these boats; but, until such practical experiments have been made, I do not think one can altogether receive, even with all the great experience and ability that Captain Jaques has, and the confidence he possesses in these boats, his statement of what they actually will do. If we knew what they had done, then we should have confidence in them. We know that the British Admiralty in trying guns, and that sort of thing, have placed hulks out and have actually fired into them, to see exactly what effect they would have. It seems to me that the expense would be so trifling that, if there is this perfect confidence in these boats, surely that trifling expense might be incurred, and it would satisfy the designers of these boats, the builders, and the country that they are an actual success, and can accomplish what is expected of them. I do not know if Captain Jaques can tell us whether any such experiments have been made; but, if so, it would raise my appreciation of these boats very much indeed compared to what it is now.

Professor J. H. Biles (Member of Council): Sir John Hay and Gentlemen, I have listened with a great deal of attention and pleasure to this interesting paper of Captain Jaques. It has relieved the seriousness that we have had to do with in the former papers. I think he is to be congratulated that he has not introduced either "x" or "y" into the paper. This question of submarine boats is a very interesting one. It has always seemed to me to be a curious thing that a torpedo sent from a ship should be made so as to maintain her position below the water, and her direction, and that, so far, we have not been able to get a torpedo on a larger scale, plus the brains that a man can carry with him in her, able to travel successfully below the water. It seems to me that, if we can get a mechanical automatic contrivance to go accurately and safely to its destination, as a torpedo can, there is no reason, on the face of it, why a larger sized boat should not be able to go, when you have, in addition to the automatic part of it, the directive and controlling power of the brain of a man inside. Of course, the conditions have to be made so that the man can live, but those surely are not insurmountable. It seems to me to be, perhaps not in the immediate future, but in the distant future, quite possible to carry a considerable amount of the sea-borne commerce of a nation in a submarine or semi-submarine type of boat. The conditions for working below water, we are led to believe from the ordinary theory of resistance, are much more favourable than the conditions for working above water. If we can only get over the little difficulty of the human element, and give the necessary stability to human life below the surface, then, if all we know about resistance is true, we ought to be able to get our cargo boats propelled for much less horse-power than they are propelled when on

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the surface, especially in bad weather, because bad weather certainly would not affect submarine boats so much as boats on the surface. That leads me to ask whether Captain Jaques can give us any positive and actual information as to the actual resistance of a submarine boat. Do the results obtained as to the relations between the power and the speed in any way confirm the results one would expect from the ordinary stream-line theory which leads us to believe that the resistance of form in a submerged vessel is a negligible quantity? There is one reason perhaps why this country is not so ready to adopt a submarine type of boat for warfare, because I notice in the beautiful diagram which Captain Jaques has shown us that he invariably carries a flag-staff and a flag. I do not see how any submarine boat can begin to do its work in a submarine manner unless it hauls down its flag, and I do not think the people of this country are prepared to undertake anything in warfare when the first condition is that the flag should be hauled down.

Captain KRILOFF (Associate): Sir John Hay and Gentlemen, I beg your permission to say a few words, in order to make an indication which will perhaps be useful to those who may try to elaborate the project of a submarine boat. In 1892 I had to assist my friend Drzewiecki, who was charged by the Russian Government to elaborate such a project. He afterwards slightly modified this project, and offered it for competition in Paris, and it is known that M. Drzewiecki obtained the highest reward. About others there arose the difficult question how to calculate the proper dimensions of the frames so that they could resist an external pressure of 60 ft. of water (it was one of the data) tending to collapse the boat. The most appropriate form for this resistance is the circular one; but, from other considerations, elliptical forms of the boat's cross sections were found more convenient, and thus the resistance to collapse of an elliptical and of other more complex forms had to be calculated. I must confess I was really glad when in Volume V. of Résal's "Traité de Mécanique Générale" I found a completely elaborated solution of such a problem. This solution, of course, was but an approximate one, but Résal's authority in such matters is unimpeachable. If this indication will be useful to anybody, the few minutes of your time which I have taken to make it will not have been spent in vain.

Mr. J. MACFARLANE GRAY (Member of Council): Will Captain Jaques tell us how often he has been down himself in the submarine boat? He may have gone down once not knowing what it is like. Will he tell us how many times more than once he has been down? I should like to know.

Mr. P. S. PILCHER (Associate): I think it would be of interest if Captain Jaques would tell the meeting how far the boat has really gone underneath the surface of the water, and how far it travelled from the time it went down to the time it came up again.

The CHAIRMAN: What is the radius of efficiency?

Mr. PILCHER: What is the distance the boat has travelled really underneath the surface of the water? I do not think it is stated in the paper.

Captain W. H. JAQUES (Associate): Sir John Hay and Gentlemen, you have all been good enough to ask me a good many conundrums, and if I cannot answer them now I will do so before the paper is printed. With regard to what Mr. Barnaby has said, I have no desire to convert him from taking passage in such a splendid ship as the *Majestic* even to cross the Channel in a submarine boat. In connecting myself with the question of submarine navigation, as I have done very seriously for the past nine months, I can hardly hope to succeed in building a perfect submarine boat; but I do believe that what we have recently accomplished is going to have a radical effect in modifying the present

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type of torpedo-boat destroyers, and, with all due respect to the great and very marked developments that have been made in torpedo-boat construction in the last few years, it is very evident that the torpedo-boat destroyer has made the ordinary torpedo-boat a thing of the past. I believe that the submarine torpedo-boat, in some form, is the type that is to come. Referring again to the *Majestic*, I went down in a Nordenfeldt boat some years ago, and have also been in the *Holland*, and I did not have so long a period of comfort as I did in coming across the ocean in the *Majestic*, which I did for the express purpose of attending this meeting, and also to have the pleasure of meeting my colleagues and friends at the banquet you had the other night, but we were unfortunately delayed on account of continuous bad weather. With regard to what Mr. Barnaby has said as to the difficulty of finding an enemy, that is one reason why we have been endeavouring to make this submarine boat a perfect fish, so that it can disappear and come to the surface at will. Anybody who has had to do with submarine boats knows that you can see no further through the water than you can through a stone wall. The only thing more difficult to see through is a London fog in November. As far as submarine guns are concerned, my associations with Captain Ericsson, and my subsequent work in developing submarine artillery in the United States, practically proved that there is no difficulty whatever in discharging submarine guns; the only disappointment is we cannot get as great a range under water as we would like.

Mr. BARNABY: It was the aim I referred to.

Captain JAQUES: As the gun is in a fixed position, the aim is governed by the guidance of the boat; the longitudinal axes of the guns are in the longitudinal axis of the boat. In thanking Mr. Martell for his remarks, I would say that with a boat of much less efficiency than the *Holland* a hulk has been blown up. We have no doubt as to that part of the system. We have been devoting our energies more to the diving power, and to obtain absolute control of the diving mechanism of the boats. As far as my confidence in submarine torpedo-boats is concerned I can only say that not many years ago I resigned from the Naval Service to introduce machinery into the United States for the manufacture and development of armour and heavy guns, and a great many of my good friends in England, among them Mr. Ellis, Mr. George Wilson, and many others, discouraged my advocacy of plain steel in contradistinction to that of British compound armour. It is not necessary, I think, for me to say anything else than that my confidence in that case was thoroughly endorsed by the type of armour that the world subsequently accepted. In relation to the test in England I would also like to say to Mr. Martell that I have already been in correspondence with the Wilson Line of steamships for the purpose of bringing the *Holland* to Southampton for a trial, and if it had not been for the present situation in the United States that would have been done. It was my intention to have had the experiments made near London, which is the Holy See for the development of all these things. I thank Professor Biles for calling attention to the relief from the seriousness of our scientific meetings, and I can only reply that I desire to keep up this cheerful condition until I convince you all that the submarine torpedo-boat is a very great success. I will say, further, that we submerge with a flag flying, because we, like the people of Great Britain, do not intend to haul down the flag before we go into action. I cannot give you any positive information with regard to resistance under water, but I will say that the *Holland*, instead of being a disappointment, has been an agreeable surprise to our calculations. Replying to Captain Kriloff's remarks, although we believe in the construction of our boats, we have taken every precaution against collapse. I shall be most happy to get the information he proposes to give the Institution. I anticipated Mr. Macfarlane Gray's question some years ago by going down in an English boat built at Barrow, the *Nordenfeldt*. I

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commenced my submarine experiments then, and I have not been afraid to continue them in the *Holland*.

Mr. MACFARLANE GRAY: The question is, whether one is more apt to be sea-sick in a submarine boat than on the surface.

Captain JAQUES: The older we get the more we desire personal comfort, and I must say that I prefer the *Majestic* to the *Holland*. With regard to Mr. Pilcher's question, as to how far we have travelled under the water; we have made many dives and runs of 400 yards. Those have been repeated on many successive days. I think I may say finally, Sir John Hay and gentlemen, that with the encouragement you have all given me this evening, especially that of Mr. Yarrow, and the introduction of Sir Edward Reed with regard to the value of rudders (as we intend to control our boats almost entirely by rudders), I will simply call attention to the fact that this model which is on the table before you, and which was reproduced from Mr. Nixon's working model, represents, not only a submarine boat that can dive, and can look, and act like a porpoise, but does not have to turn on its side, or back, before it enters on its field of destruction like a shark, and its stability in all its trials has been most satisfactory. Sir John Hay and gentlemen, I thank you all very much for your attention and consideration.

The CHAIRMAN (Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I think we must all thank Captain Jaques for his most interesting and instructive lecture, and for the great pains he has taken to bring it here and show it to us. I wish he had been with us when we were having a subterranean dinner, which he would have found even more agreeable than the submarine boat. We dined, I think, 50 ft. below the level of London, where we hoped to have had the pleasure of dining with him; but unfortunately missed Captain Jaques, and we had all the comforts of the *Majestic*, and I can only sincerely wish that Captain Jaques had been there also.

Captain W. H. JAQUES: Sir John Hay, I thank you for the further encouragement which your subterranean banquet has provided for the accomplishments of the submarine boat.

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ON THE DIRECT ATTACHMENT OF COPPER SHEATHING PLATES TO THE HULLS OF VESSELS.

By Leopold Roper, Esq., Member.

[Read at the Thirty-ninth Session of the Institution of Naval Architects, April 1, 1898; Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C L., F.R.S., Vice-President, in the Chair.]

I feel somewhat diffident in offering this paper to you, following the very able paper read by Sir William White before the Institution of Naval Architects during the meeting in Paris in 1895.

It is not my wish, or intention, to in any way controvert the statements made by Sir William White, to whom and his able colleagues we are all greatly indebted for the valuable and most interesting information on the subject given in the paper; but, on the other hand, I am of opinion that the national importance of the question, the length of time I have devoted to studying and working out the best method of direct plating, and the great benefits to be derived from its application, sufficiently justify my presumption in laying before you the details of a system, the many decided advantages of which I trust will meet with your recognition and approval.

Without entering into any historical dissertation on the subject (a most lucid *résumé* will be found in Sir William White's paper), experience has taught us that, whether applied to war or mercantile ships, that system of sheathing which most nearly conforms to the following requirements will ultimately prove itself the most serviceable and economical in use, and, I venture to predict, will also secure from shipowners the largest share of attention.

Briefly, these requirements are as follow :—

(1) The system used must be relatively cheap, both as regards initial cost and maintenance.

(2) The sheathing plates used must secure to the vessel the power of keeping the sea for long periods without serious fouling, and its consequent loss of speed and waste of power. At present, and commercially speaking, this proposition admits of but one corollary, namely, the employment of copper plates, zinc standing self-condemned.

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(3) There must be complete provision against the setting up of galvanic action between the various elements of the system, and entire absence of metallic connection between the copper plating and the hull.

(4) The entire system must lie "snug" to the hull, that is, there must be the minimum of projection of the parts from the plating of the vessel.

(5) While retaining the same thickness of copper, the other parts of the system must be reduced to the minimum of weight compatible with rigid efficiency.

(6) Fewness of movable parts and adaptability to easy inspection and rapid repairs.

(7) The system throughout must provide no space for water to lodge between the skin and sheathing plates.

(8) No materials capable of "splintering" or of becoming saturated to be employed between the skin and sheathing plates.

(9) The system must be such as to confine the effects of any local injury to the least possible area; and

(10) All parts of the system should remain intact and unaffected by the torsional and other stresses experienced by a vessel during severe weather at sea.

Now, it might well be said, after a casual consideration of the points raised, that a system capable of satisfactorily fulfilling all these requirements is attainable only by the idealist, but I hope that the following statements, aided by the diagrams now before you, will prove that each and all of these requirements may be effectually provided for in a very prosaic and matter-of-fact manner, while, at the same time, I submit that in all its details, and in its entirety, the system I now lay before you approaches nearer to the "ideal" than any other with which I am acquainted.

A reference to Plate LVI. will show the method of construction followed in Roper's system of coppering steel ships, and it may be well, at the outset, to call attention to the fact that no sheathing wood is employed. This means, taking Indian teak, of four inches thick with a specific gravity of ·88, and allowing the same thickness of copper in each case, a saving of 17½ lbs. weight per superficial foot of sheathing for wood alone. The sheathing shown on the diagram weighs 3 lbs. per superficial foot, and the entire projection from the ship's side does not exceed three-eighths of an inch, as against the 4 in., and upwards, which usually obtains where copper-faced wood sheathing is fixed.

To prepare a vessel for this system she is first coated to the required height with a layer of Roper's insulating material. This material is no more difficult of applica-

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tion than a coat of ordinary paint, which it replaces, and, when dry, a layer of prepared water-proofed felt is put on to the ship's bottom, and she is then ready to receive the copper plating, which is attached to her in the following manner:—

The brass "grids" have drilled in them a number of small holes corresponding to those in the copper plates, and the outer face of a grid and the inner face of a copper plate having been coated with insulating material, the two are placed in juxtaposition and riveted together with a number of the small copper rivets shown, the rivet heads being "flushed" to the outer face of the copper plate. As will be seen, the plates are so arranged on the grids as to ensure that each overlaps those next it on the top side and after end, thus preserving absolute water-tight continuity of the sheath plating.

The six holes for the corresponding number of brass securing screws, or bolts, B B, having been drilled "fair" through plate and grid, and countersunk, their positions are next accurately marked off on the hull plating, in which the necessary holes are then drilled and tapped.

The spaces marked A A in the grids are now filled up with hard packing pieces previously coated all over with insulating material; this is shown by the enlarged cross sections taken on the lines A B and C D, and the inner face of the grid having been coated with the same material, the entire member is ready to place *in situ* on the hull, where it is secured by the brass screws, or bolts, B B, in the manner shown.

It should be stated that it was at first considered necessary to insulate the brass screws, or bolts, from the copper plates by surrounding their heads with a cup-like washer of insulating fibre, but experiment has proved that dipping the screws, or bolts, in the Roper insulating composition is sufficient to ensure perfect insulation between the parts.

Reverting to the requirements of an "ideal" plating, as set forth at the commencement of this paper, and having before us a description of the method of constructing and applying Roper's system of coppering, let us now consider how nearly this system appears to satisfy those requirements.

First and foremost comes the (from a shipowner's point of view) paramount question of initial cost and subsequent upkeep. A series of carefully prepared estimates warrants me in asserting that, as regards first cost, my system can be fitted to any vessel for 50 per cent. less outlay than is involved in fitting the most simple form of combined wood and copper sheathing at present known. As there is absolutely nothing in the Roper system to give out, perish, or wear away, it is most difficult to see where any item for upkeep can fairly come in; but, on the other hand, I have the authority of Sir William White for stating that "wood and copper sheathing necessarily involve . . . . some addition to the charge for maintenance."

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As regards the second point, it is, I think, now conceded on all sides that copper plates are a *sine quâ non* in any system of sheathing that lays claim to efficiency.

The third requirement is met by the thorough insulation obtained by coating with Roper's insulating compound each and all of the parts, screws, &c., thus breaking the metallic contact of one from the other, and of all, in turn, from the hull; while the layer of felt and the hard insulated packing pieces in the grids effectually prevent any possibility of metallic contact between the copper plate and the hull. The edges of the grids being, as it were, cemented one to the other with insulating material, and the packing pieces fitting tightly into the grid spaces, these, together, form a third watertight skin beyond the hull, the first being the coating of waterproof insulating composition, and the second the layer of waterproofed felt.

That this system has, by reducing the total outward projection from the plating of the vessel to within $\frac{3}{8}$ in., gone nearer to complying with our fourth requirement than obtains with any other system is, I think, self-evident, as is also the fact that this approach to the minimum projection is not attained by any sacrifice of efficiency. All the component parts of the system have been carefully calculated out to give the requisite strength, and in these calculations a large margin, or factor, of safety has been duly provided for.

Let us consider, by means of a typical example, what is gained by this comparative thinness of the Roper system of coppering.

Taking the midship section of a vessel having 46 ft. beam, and drawing (amidships) 22 ft. of water, this gives us an immersed midship section of 936 sq. ft. The Roper system of coppering increases the beam to 46 ft. $0\frac{3}{4}$ in., and the immersed section to 938·4 sq. ft., or an increase of, say, $\frac{1}{4}$ per cent. The combined system of wood and copper sheathing increases the beam to 46 ft. 8 in., and the immersed section to 966 sq. ft., an increase of, say, 3 per cent.

This increase of midship section means, of course, with the same engine power, loss of speed; or increase of engine power, if speed is to be maintained constant. The vessel referred to when making 12 knots indicated 4,130 H.P., or 4·4 H.P. per square foot of immersed midship section. If this section is increased 30 sq. ft., it clearly would need 132 I.H.P. more to maintain the 12 knot speed, whereas with the Roper system and its extra 2·4 sq. ft. of midship section only 10·6 extra indicated horse-power would be needed to keep up the 12 knots.

Taking the entire immersed surface, or "wetted skin" area of this vessel at 10,000 sq. ft. (these figures are not exact, and are used solely for purposes of comparison), the deadweight addition, due to fixing the Roper system of sheathing over that area, would be 30,000 lbs., say $13\frac{1}{2}$ tons, as against 100 tons, the deadweight addition involved by

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fixing the 4 in. combined wood and copper system; figures which go to prove that 85 per cent. of the total weight of the present combined system of sheathing may be saved by using the Roper system.

The figures just given in reference to the additional deadweight on a vessel due to fixing the Roper system show that it, of all approved methods, nearest conforms to the fifth requirement.

As regards the sixth requirement, fewness of movable parts may certainly and justly be claimed as a leading feature of this system, and when it is borne in mind that it is only necessary to withdraw six screws, or bolts, to admit of the removal of an entire section, measuring 48 in. by 14 in., it will be admitted that easy and rapid inspection, or repairs, can readily be carried out, and that without having to call in the aid of skilled labour. Compared with this ease and simplicity, how almost appalling appears the task of stripping off an equal area of any of the combined wood and copper sheathings with their multiplicity of hidden and "ungetatable" bolts, nuts, screws, studs, &c.

As regards repairs, it would not be unreasonable to say that, to replace an equal area of damaged sheathing under the Roper system would cost only about one-fourth as much as in the case of a damaged copper-faced wood sheathing; and similarly, a simple inspection of any part of a hull fitted with the former system could be made at about one-eighth or one-tenth the expense that would be incurred in removing and replacing the combined wood and copper sheathing.

It needs but a cursory examination of the diagrams now before you to show that this system completely meets the seventh of our assumed requirements. Not only is there an entire absence of any space in which water could accumulate between the skin and sheathing plates; but, even assuming any of the copper plates to be damaged or become "leaky," the total absence of wood sheathing admits of no saturation and ultimate rotting away of the backing; while the ample provision made for perfectly insulating all the parts precludes, as before stated, the possibility of galvanic action being set up should water find its way between the plates. Again, the substitution of brass screws, or bolts, and copper rivets, throughout the system, for iron bolts, studs, screws, &c., prevents that serious and rapid corrosion of fastenings, of which, in his paper, Sir William White justly complains. Furthermore, the absence of dry wood removes the danger due to its locally expanding about the neighbourhood of a leak, or injury to the copper sheathing, so aiding to extend the ruptured part by bringing extra pressure to bear on it.

As in this system of direct attachment of the sheathing plates no materials capable of "splintering" are employed, this source of widespread destruction does not exist, and it is therefore clear that all injuries must be confined to the least possible area; thus the Roper system satisfactorily complies with requirements (8) and (9).

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Were it necessary to here set forth the commercial advantages and pecuniary gains following on the copper sheathing of merchant vessels, I could not do better than quote that part of Sir William White's paper, wherein he shows that, notwithstanding "the improved anti-corrosive and anti-fouling compositions now available," and "increasing facilities for docking" . . . . "some lines find it advantageous to dock their vessels four times a year on an average" . . . . and mercantile shipowners interested in the question of sheathing should further, and carefully, consider the following statements made by Sir William White in the course of his paper: "Careful observations made in the Royal Navy on ships employed in European waters have shown that, after five to six months afloat about 20 to 25 per cent. more power was required to maintain ordinary cruising speed than sufficed with clean bottoms; after ten to twelve months afloat this increase of power becomes 40 to 50 per cent." Again, Sir William says, "The degree of foulness attained by unsheathed ships varies very greatly; but it seems to be generally agreed that in high-speed ships docking and cleaning must, as a rule, take place twice or thrice a year in order to maintain speed and economy of coal." If anything further were needed to show the advantage of copper sheathing (if only from the coal-saving point of view) surely it is supplied by Sir William White's further statement:—"On the contrary, copper bottoms usually keep fairly clean for a considerable time; and I have seen sheathed vessels docked after one and a half to two years' service, chiefly in hot climates, with practically clean bottoms."

Finally, Sir William White tells us "wood and copper sheathing necessarily involve a very large addition to first cost"; but, unfortunately, he does not furnish us with any exact figures. These, however, are given as regards some of Her Majesty's ships in a brilliant paper, entitled "The Cost of Warships," read by Professor Elgar at the same meeting of the Naval Architects in Paris. From this paper we learn that "about £17,000 requires to be allowed for the cost of teak and copper sheathing, extra cost of brass stem and stern posts," &c.

In conclusion, I can only state that I should be pleased, I might say *very pleased*, to sheath, as efficiently and durably, any vessel, war or merchant service, of equal size for half the money.

DISCUSSION.

Mr. Archibald Denny (Member of Council): Sir John and Gentlemen, Mr. Roper is an inventor, and as such I have a good deal of sympathy with him, for I have been an inventor myself; but I have also been the victim of inventors. Some little time ago a gentleman conceived the idea of not only coating a vessel with copper, but coating it without the medium of either bolts or frames or anything else; he deposited the copper directly on the steel plates. He showed us a sample of a steel plate with the copper attached to it, which copper had been deposited electrically, and it

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certainly adhered very firmly, and was of good thickness. He explained how he intended to coat a vessel entirely by means of his system, and he was such a pleasant young man, and exhibited so much ingenuity, that I persuaded my firm to allow him to make the experiment on our steam tender, *Snark*. He was to bear all the expenses, except, I think, some £40, which we were to pay for the value of the copper, and we were to get a share of the credit if successful. Well, the weather was bad, no doubt, and he worked under great disadvantages; but, while his methods were extremely ingenious, and appeared all right on paper, they were not so successful in practice, and before the *Snark* was more than half coated he got into financial difficulties. As the firm thought it would be much worse for the *Snark* to be half coated than to be wholly coated they therefore financed the young gentleman. I may say that that money has been written off, and the *Snark* is now re-coated with paint, and I do not know, if we came to try and sell her now, that Mr. Martell would quite approve of the condition of the surface of the plates. Now that is an actual experience of a system which looked so well that people who are not considered to be wholly lacking in judgment and experience were under the impression it would be a success. I think it will be admitted that, if you could coat steel plates with copper, entirely and absolutely, without exposing any iron or steel whatever, and with copper amalgamated practically with the steel, you would be in a good condition. I do not know whether Mr. Roper has had the opportunity of experimenting in the way that the young gentleman I refer to had. Probably not, because, if so, Mr. Roper would doubtless have stated it in his paper. For Mr. Roper's good I would warn him to be careful how he invests his own money; it is not so important to him what he does with other people's money, within certain limits. I am very much afraid he will experience great difficulties in insulating thoroughly this copper sheathing. He says he has made accurate experiments with "Roper's" insulating material, and he has found it unnecessary to use the cups that he, at first, thought would be required; but he has not explained the nature of his experiments, and if they were what I may call quiescent experiments—simply a piece of plate put into a bucket of salt water, and allowed to remain there—I am afraid the experiments have not been sufficiently complete. You must consider the damage that might result to any part of the coating from the docking of the vessel, a very simple and necessary operation, but you must put blocks and shores underneath the vessel. Of course, Mr. Roper's answer will be at once "that his material is so very solid that there will be no chance of damaging it"; the other man also thought that his method was all right, and so did I before it was tried, but it was not. It would be much more satisfactory if Mr. Roper could have told us that the steamship "so-and-so" has been coated by his system—insulated with "Roper's" insulating material—and that it was a success. I am sorry if Mr. Roper thinks I am discouraging him, but I know how inventors (having been one myself) are carried away with their ideas. I only wish, not to absolutely discourage him, but to warn him that, notwithstanding all his ingenuity, after all the only test is to coat an actual vessel. We all admit the value of copper sheathing, and if Mr. Roper, or anyone else, can discover a good and cheap system for coating vessels with copper, there is not the slightest doubt that our Admiralty and the Mercantile Marine, on certain occasions, will adopt it and that man will make his fortune.

Mr. W. E. Smith (Member): Sir John Hay and Gentlemen, I entirely endorse everything that my friend, Mr. Denny, has said with reference to the general aspect of this question. There can be no doubt, of course, that if Mr. Roper's system can be shown to be a complete success as regards its ability to keep ships' bottoms clean and free from weeds, and, at the same time, leave the steel hulls entirely uninjured, his system must be admitted to be preferable to that now in vogue. The question of the sheathing of ships is, at the present moment, of very much more importance to the

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Admiralty than it is to any other shipowner, on account of men-of-war having to be away so much longer from docking accommodation. On this account many of them have to be sheathed, and the question of a suitable system of sheathing is one which is always before the Admiralty in some shape or another. Mr. Roper was good enough to bring this matter under the notice of the Admiralty some few years ago, and to show us there, as he is showing us here, the details of the method of attachment. So far as I can see, there is practically nothing new in the system that he has shown to-night different to what he showed us then. The whole crux of the matter, however, is this: What we want to know is, as Mr. Denny says, whether the system has been actually applied to any ship; whether the system stands the ordinary knocking about that a ship naturally gets; and whether, if this be so, the proper structure of the ship is left entirely uninjured? Now, at the present moment, the Admiralty has a system of sheathing which is certainly more costly than that proposed by Mr. Roper. The present Admiralty system was introduced some few years ago, after a long experience of a still more costly system, and at the time of the introduction of the present system some hesitation was felt whether we were not going too far. For the purpose of ascertaining the facts we instituted a system of periodical inspection, at short intervals, of the bottoms by taking off small portions of the planking and copper. This examination went on for some three or four years, and the invariable result was that the steel structure of the ship was found in a perfectly satisfactory condition, and that no damage of any kind had been incurred. We had a great many ships running for some years, and it is perfectly true to say that not one of those ships experienced the slightest damage of any sort to the structure of the ship proper on account of the system at present in use. That being so, and having regard to the probability of some of the many thousands of the bolts in Mr. Roper's system attaching the copper to the bottom making metallic contact between the steel hull and the copper outside it, I think we should be acting imprudently if we gave up the present Admiralty system for any system of this sort. I think the system advocated in this paper is one that an ordinary practical shipbuilder, who knows what ships have to stand, could not recommend with any prospect of success. I think this matter so important that, unless we get actual experience showing the system is successful, the probability of non-success is so great as to make it extremely imprudent for anybody to set to work with the view of adopting the system for actual use in vessels such as H.M. ships, that are required to keep the sea for long periods without the necessity of docking.

Sir Edward Reed, K.C.B., F.R.S. (Vice-President): I should like to say one or two words. In the first place, one word about the cost. Mr. Roper very properly included brass stern frames as being requisite for the ordinary system of sheathing, but such frames would be just as essential in his case as they are in the other. He could not copper a ship in his way, I should imagine, with security, without adopting the brass stem and stern posts; at any rate, I think he would find it a very difficult thing to sheath steel stem and stern posts satisfactorily by means of his system. Another thing, I do not know how he would overcome the difficulty of having to deal with the outer and inner strakes. When you lay over the bottom of a ship a layer of wood, you can easily deal with the outer and inner strakes of the steel bottom, because you simply vary the thickness of the wood you put over to suit that irregularity; but I do not see anything in Mr. Roper's paper as to how he proposes to deal with the matter. That seems to be a very great difficulty in the way of introducing this thin substance between the outer sheathing and the steel bottom. Lastly, I think we ought to know more about the material he proposes to employ. I confess I do not know much about it myself.

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Mr. Roper: The insulating material?

Sir Edward Reed: Yes. I do not think it quite fair to Mr. Roper, as a young man, to charge him with not bringing a successful ship to our notice. I know that in some Institutions, that of the Civil Engineers, for instance, there is a standing rule that no paper should be admitted that does not describe an actually executed work; but we have not got that rule. We are a little more liberal in holding out a friendly hand to a man at rather an earlier stage than that, and I do not know that we should be altogether disposed, all of us, to discourage an inventor because he is unable to say that he has actually overcome all the preliminary difficulties, financial and other, and obtained a success on a large scale. I think we ought to be a little more sympathetic in that respect; but, on the other hand, Mr. Roper must bear in mind that it is a serious matter to come and seek to upset a well-established and most successful system—a system that has been so successful as Mr. Smith has just explained to us, and his experience is derived from an enormous scale of operations; it is a very serious thing for him to come and expect a number of men, accustomed to carry out operations in a known and thoroughly successful manner, in which great experience has been had, to accept his invention, without being able to back up his claims by specific, even if small and limited, experience.

Captain G. H. Little (Visitor): May I say there is one class of ships as to which I think such protection would be of great advantage, provided that it could be satisfactorily applied, and that is to cable steamers. I have had some experience in these vessels, and it is a common practice with them to lay cables over the bows, and to lie up for a long period of time in harbour. It seems to me in laying the cable in this way over the bows you would scour off this sheathing in a short space of time. It also seems to me that when the ship was bringing up very rapidly, and letting go her chain cable, it would strip off the sheathing very rapidly. In going through the Suez Canal, or up the Baltic, it is a very common thing for ships to ground, and if they grounded on the hard bottom of the Suez Canal, or even on some of those sands which are met with in the Baltic, it seems to me this thin sheathing would be rubbed off and the water admitted, and oxidation set up very rapidly.

Mr. Leopold Roper (Member): Sir John Hay and Gentlemen, I thank you for the patient hearing you have given my paper. It appears to me that the whole, or very nearly the whole, of the remarks that have been made by the several speakers centre themselves on the question of galvanic action. At this late hour I must endeavour to occupy just the fewest possible moments in reply. I may say that, up to the present, I have not had the honour of fitting my system of coppering to any large ship; but, as I take it the most important point will be the question of insulation, I beg to submit that the thorough insulation of the hull plating, by first coating it with my solution and then applying the felt, which is itself coated on both sides, thoroughly breaks all metallic contact between the hull and the copper. Again, if you consider the mechanical method of attaching the "grid" and plating, both coated with the insulating solution on each surface, it will be apparent, I think, that, insulating as I do, I provide a reliable safeguard against metallic contact, as there are five distinct layers of insulating material between the hull plating and the copper. As each of these layers would offer many ohms resistance to the passage of the current, and as it is well known that a copper and steel couple excited by sea water does not generate current sufficient to overcome more than a few microhms, it is evident that, so long as a single layer of the insulating material remained intact, its resistance would be many thousandfold more than sufficient to prevent any galvanic action being set up. Referring to the remarks made by Mr. Smith, I need scarcely say that the practical application of this, or any other system of coppering to a full-sized vessel, even to a torpedo-boat destroyer, does not come within the scope of a private individual, but the results of prolonged

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experiments on a small scale show that all the results of galvanic action have been defeated; this I have conclusively proved, else I would not have submitted my paper to the Institution.

Mr. DENNY: Might I ask Mr. Roper what experiment he has submitted the process to?

Mr. LEOPOLD ROPER: I have submitted built-up sections to the prolonged action of sea water in a large tank, the period being upwards of two years, and I am quite prepared to let Mr. Smith, or the Admiralty authorities, have these sections of the plating put down in the basin in Portsmouth Dockyard for any reasonable testing they may care to submit them to. In the one section the plating was screwed up tight to preclude any admission of water, in the other the water could enter between the felt and the steel plating, but in neither case was any galvanic action set up. I submit that my method of attaching the copper to the grid is much stronger than when the copper is merely nailed on to the wood backing. As to the thousands of bolts Mr. Smith referred to, I have got fewer rivets fastening the copper to the grid than there are nails used in fastening the copper to the teak sheathing as at present used, while the direct attachment of the grid to the hull is effected with fewer and cheaper bolts than are needed to hold up the timber backing of the present method of coppering; and I further contend that my system, projecting as it does only $\frac{3}{8}$ths of an inch beyond the hull, is a great advantage when compared with the existing four inches beyond the hull. There is another most important thing referred to by Sir Edward Reed, namely, the inner and outer strakes of the vessel; these I suggest should first be made flush by filling in the inner strakes with teak boarding of the same thickness as the plating, this will form a solid and flush surface, and enable the vessel to take the blocks when docking without fear of damage, the teak boarding being, of course, previously coated on both sides with my solution. Sir Edward's remarks as to brass stem and stern posts apply to any system of coppering, and these parts could be readily copper covered by my system, even if they were of steel. I am confident that, if you insulate as suggested in my paper, there would be no danger of galvanic action setting up at any part of a ship. Of course I do not claim for my system perfect immunity from dangers common to all systems, such as running on rocks or grounding, but I maintain that a system, all the parts of which are metallic, would be less susceptible to injury even in these contingencies than would the present system, relying for strength as it does on a wooden backing. I am prepared to let anyone have a plate, or a series of plates, to experiment with, and I am quite sure they will find, it they try it, as I have tried it, that this method of coppering has overcome the galvanic action. I thank you, gentlemen, for your patient hearing.

The CHAIRMAN (Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I am sure you will all wish Mr. Roper long life and success in his efforts to perform a very useful duty. If he has not quite convinced us all, he has put us in the way to satisfy ourselves. I trust eventually he may succeed. He is, as he has said, a young beginner in art and science, and we thank him for coming here to-night and giving us this opportunity for discussion.

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PRESENTATION TO THE PRESIDENT, THE RIGHT HON. THE EARL OF HOPETOUN, G.C.M.G.,

At the Annual Dinner,

Held on Wednesday, March 30, 1898, at the Grand Hall, Hotel Cecil.

Sir Edward Reed, K.C.B., F.R.S. (Vice-President): My Lord and Gentlemen, the programme of the proceedings of these meetings will have prepared you to-night for a double duty on the part of someone. That someone happens, by the favour of the Council, to be myself. That double duty consists, I will say at once, in proposing the health of our noble President, and performing a pleasing ceremony. It seems a little strange that one who was present at the initiation of this Institution should be proposing to-night a toast, and taking part in a ceremony which is certain to receive the most cordial support and the approbation of every gentleman present in the room. When this Institution was founded, we all felt that naval architects and marine engineers could get on, for their own immediate purposes, perfectly well by themselves; but we felt that, for wider purposes, and in view of wider objects than our own, we should do well to extend our boundaries beyond shipbuilders and marine engineers, and should seek the support and assistance of naval officers and those representatives of the Mercantile Marine who are in such intimate relation with, and who so much depend upon, the progress of naval architecture and marine engineering; and that we should go even beyond that limitation, and should seek for the counsel, the assistance, and the support of men engaged in great duties of the State in respect of our naval interests. It has been a matter of delight to all those who have been from the first in association with this Institution, and, indeed, to all of us, to remember that our first President—though no naval architect, and though no marine engineer—was the First Lord of the British Admiralty, and charged, therefore, with the highest responsibilities that any man can be called upon to sustain in connection with the traffic and the safety of the sea. I daresay it will be acknowledged by old and distinguished friends like Sir John Hay (who was one of the first of the naval officers of the Council) that, from the foundation of this Institution until the present moment, the naval architect and the marine engineer have always been in the highest degree solicitous of the assistance of the naval officer and the Lords of the Admiralty, and among our brightest recollections is that of having had for our first President Sir John Pakington, afterwards Lord Hampton, who gave us the utmost support which a capable and patriotic mind could bring to our assistance. We have at times—as I for one will frankly confess and acknowledge—thought that, however necessary to our existence statesmen, and politicians, and political heads of departments may be, it might be well for us to consider whether it was not best to make ourselves strictly a professional and technical institution; and the Secretary, I think, with that frankness with which he is fortunately endowed, will acknowledge that there was a moment when I, looking round upon the distinguished naval architects and engineers who assisted us from the first, thought it might be proper to secure for some of them the highest position which the Institution can offer. But, I may be allowed to say

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to-night that that idea passed away when I heard of the nomination of the noble Earl who presides over us as the probable President of our body. I happened, gentlemen, to be at a dinner given at the St. George's Club to the Earl of Hopetoun, when he had been selected by Her Majesty to represent her as the Governor of one of our most thriving and important colonies, and when I listened to the speech which he made on that occasion I came to the conclusion that I was in the presence of a man who would "go farther." I really do not know what our foreign friends may think, and I do not know what many of ourselves may think, but I am one of those who consider that it is a fortunate thing that in this country bodies such as ours, so essentially democratic, can seek and accept the support of men who, by birth, education, and experience, are more associated with the aristocracy and the Court, and leading politicians, than with associations such as those which you and I are accustomed to follow. There is no member of this Institution, and I feel persuaded that I shall not exact too much from your complacency when I say there is no one in this room who will doubt that we did a wise and a proper and a successful thing in selecting for the presidential chair of this Institution the distinguished nobleman who now presides over us. I will not conceal from myself, or from you, that we as a body of men trained in exact science, and bound by every law of our profession to be loyal to the laws of nature, do look for strong sense and for loyalty to what is right and true in the persons of our Presidents, and I am ready to admit, after sitting twenty-one years in the House of Commons, that it is not invariably to political persons that I should look for the exemplification of that loyalty. But we, as a nation—and no doubt other nations besides ours—we as a nation, I believe, are able to rise above all narrow and limited considerations, and are prepared, in all the great work of the State, to accept the best and most capable men that we can command to do the work that ought to be done, and I can say for myself that, when this Institution had had the experience of a single sitting, one set of meetings, under the presidency of the noble Earl who did us the honour to accept our chair, we had all reached the conclusion that we had not only made no mistake, but had achieved a great and remarkable success. I never felt that in the earlier days of his Lordship's presidency more strongly than when we were invited to Germany. There we had to submit to the heat of hospitality, of which our friend Herr Laeisz is the embodiment—the true and worthy and splendid embodiment—and in Germany also we had to sun ourselves in the brightness of Imperial favour, and to be received by the great German Emperor—a man who is subject to no criticism of mine except that which bears upon the unusual and remarkable versatility of his mind, character, and accomplishments—qualities which ought to be acceptable to all of us in these humdrum days—when we had in the splendour of the German Emperor's reception to submit ourselves to the circumstances of that time, we were all delighted to know that, though the Imperial smile shone upon us brightly, and though the hospitality of Germany could hardly be measured or fathomed, we had at our head a man in whom we could repose implicit confidence to give the necessary and right responses to the favours showered upon us in that country. We had the duty, and the obligation, and the very great honour of entertaining in this country last year the representatives of naval architecture and marine engineering, and the dignitaries associated therewith assembled from other countries, and were we not most delighted to know that we had at our head the Earl of Hopetoun, with all his qualities, engaging and perfectly trustworthy, to represent us, and to conduct us through the serious operations of that undertaking? Herr Laeisz has spoken to-night with abundant generosity of the reception which we gave to our visitors last year. Well, we did our best, but I venture to say that we English are not experts in hospitality. There are other nations much more given to the delicate and beautiful arts of hospitality than we are. We are, and are not ashamed of being, a nation of shopkeepers, and a nation of shipbuilders, and a nation of

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marine engineers. If we perform hospitality, I admit that we do it from the fulness of our hearts, but that we should perform it successfully is far beyond our habits. Now, on that occasion we felt confident in our position, because we had the immense advantage of having at our head as President of the Institution a nobleman who was everywhere respected and everywhere had influence, from the Sovereign on the throne down to the lowest person with whom he came in contact. I, for my part, do not wish to exaggerate anything in his favour, but I cannot help thinking myself that we owe to him very much of the favour which we received from the Sovereign and from the Prince of Wales. It is all very well to think of the prosperity of our Institution, but there are many men sitting at this table who know that no naval architect and no marine engineer, however great his ability, or however marked his merits, would receive any recognition above a certain level on account of those qualities alone. I myself held office in the Admiralty for some years, and I felt all the time, not that I was one of the governing party, but that I was a man whom they accepted because they wanted him for certain purposes. But, supplemented as we were, and supported and dignified by the presence of Lord Hopetoun as our President, we were able last year to secure, for the advantage of those whom we received as well as for ourselves, the honour of being received by two of our future kings, the Prince of Wales and the Duke of York, and afterwards of having that gracious and most agreeable reception from Her Majesty herself at Windsor Castle. We owe much of that to the influence of our noble President, and we recognise in his work and service a great advantage to our Institution. Science is of no country, and of no class, and of no caste. Men of science are never more glorious and honourable than when they are upholding the principles of science, and giving to the world the results of their studies. Still, an institution like this effects larger purposes by moving in these larger spheres, and I believe there is no member or associate of the Institution who does not recognise, not merely the importance, but the agreeableness of having been represented at the great Congress of last year by such a man as Lord Hopetoun. After the congress was over—and, I must say, the congress passed off to the great satisfaction of everybody, our foreign friends being more than handsome in their acknowledgments—the Council formally considered the great services which had been rendered by the President, and, on the proposition of Mr. Martell, it was proposed and carried unanimously, "That the warmest thanks of the Council be voted to the Earl of Hopetoun, President of the Institution, for the invaluable services which he has rendered to the Institution, and for the admirable manner in which he has presided over the meetings of the International Congress of Naval Architects and Marine Engineers," and I am quite sure that, when the moment comes for you to drink to the health of his Lordship, you will rise above even the level of former toasts hitherto drunk, and give that toast the most cordial reception. But the Council went further than that resolution. The Council thought it was desirable to put on record and to embody in some substantial manner the feelings which the Institution have for him. Therefore they recommended that Lord Hopetoun should be desired to accept a small but a permanent memento of the Council's and of the Institution's gratitude and pleasure, and you see on the table before you here to-night a couple of cups which I have, by the authority of the Institution, to offer for the acceptance of his Lordship as a memorial of the very grateful feelings of the Institution to him for the manner in which he presided over us during the great Congress of 1897, and to express to him the hope that, though they may be unpretentious, they will be pleasing to him from their connection. Though they may be of little intrinsic value they will be of lasting importance as keeping before his mind—and, let us hope, the minds of his descendants—the loyal and devoted thanks of the Institution to him for his most excellent and valued services. (Loud and prolonged cheering.)

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The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Sir Edward Reed and Gentlemen, "Out of the fulness of the heart the mouth speaketh"; but with some people the heart beats faster than the tongue can wag. It is so with me, and especially so to-night. So you must forgive me if I speak with more than ordinary difficulty, for you have set a very difficult task before me to-night—the task of attempting to thank you in a few sentences for your munificent liberality, and for the more than flattering way in which my health has been proposed and drunk. Sir Edward Reed has spoken so kindly about me that I feel quite overwhelmed. I think he has over-estimated my services to you. I think he has magnified my capacity as a President. I thank him, nevertheless, for his graceful compliments, and would have him believe how warmly I reciprocate the feelings which he has expressed. Ever since I became your President you have treated me with utmost kindness and consideration. I value deeply the many signs of goodwill which you have bestowed upon me. You have always made me feel that you appreciated my humble efforts to carry out to your satisfaction the duties which your kindness has imposed upon me. You have made it unnecessary for me to have any such tangible proof of your approbation, as I now see before me, to convey to my mind that I was acceptable to you as a colleague; nevertheless, since it has pleased you to confer this magnificent gift upon me, I wish you to believe how greatly I and my dear wife will value it, and how proud those who, please God, will come after us will be in the possession of it. It is a gift of which an Emperor might be proud to be made the recipient; but, apart from its beauty and worth, I value the warm-hearted generosity and the friendship which accompany it. I am very proud to be associated with the Institution of Naval Architects, for we cannot over-estimate its importance to a country whose commerce is almost entirely a sea-borne commerce, and whose position, or, I may even say, whose existence amongst the nations of the world depends upon the strength and efficiency of its Navy. Great things grow from small beginnings, and it must be intensely gratifying to members who, like Sir Edward Reed, were mainly responsible for the foundation of the Society, to have watched its rise and development, and to note the high position it has attained. It is not given to every man to see the fruits of his own good works, and I offer my warmest congratulations to Sir Edward on being amongst us hale and hearty, and bearing the charm of perpetual youth, to witness the apotheosis of his offspring, which we may fairly say took place last summer. But I do not think that even Sir Edward Reed, sanguine as he may have been of the ultimate success of his venture, could have foreseen its reaching the level which it now occupies. It has justified its existence tenfold; it has done yeoman service to the State; it has indirectly done much to advance the cause of civilisation all over the world. It was owing to the action taken by representatives of this Society that the Admiralty were induced to found the Royal School of Naval Architecture, which school subsequently became merged in the Royal Naval College, at Greenwich; at the time this step was taken there was practically no technical school of any kind in England for the training of engineers and naval architects. But apart from this important service, the Institution has done valuable work in other directions. It draws a great number of its members from abroad, and in this respect it is quite unique, and, being in a sense an International Institution, foreign nations have derived nearly as much benefit from it as we have ourselves. May it flourish and continue the great work which it has carried on all these years! I thank you, again and again, for your bountiful goodness to me to-night, and for the loyalty which you have shown towards me as your President. I appreciate the generous manner in which you have always placed the best possible construction on all my actions and words in the past. I ask you with every confidence to continue to do so in the future.

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CONCLUDING PROCEEDINGS.

Mr. ARCHIBALD DENNY (Member of Council): Sir John Hay and Gentlemen, we have come to the end of our programme so far as papers are concerned. I do not know whether you all realise the fact that we have occupied these rooms year after year, practically rent free, through the kindness of the Council of the Society of Arts. We have been here, I am told, since the year 1860, and we owe, therefore, a very hearty vote of thanks to that ancient and honourable Society for their kindness in granting us the use of these rooms. I do not think anything I can say would make you appreciate their kindness more than I feel you must do. Other societies have rooms of their own. Whether we shall ever come to that I do not know; but, at any rate, for the present we are well and comfortably housed, and we should express our gratitude to the Society of Arts for their kindness. Therefore I beg leave to propose that a hearty vote of thanks be accorded to the Council of the Society of Arts for granting us the use of these rooms.

Mr. S. W. BARNABY (Member of Council): A characteristic of all London scientific societies is their hospitality to kindred institutions, and I think amongst the first rank of benefactors in that respect stands the Society of Arts. As recipients of this hospitality we have great cause for gratitude, and I beg to second the vote of thanks.

The vote of thanks was put and carried unanimously.

Mr. B. MARTELL (Vice-President): Sir John Hay and Gentlemen, I feel it a great honour to have the opportunity of proposing our sincere thanks to our noble President for the very able, courteous, and successful manner in which he presides over our meetings. It is needless for me, I am sure, to say anything in praise of Lord Hopetoun with regard to the office he fills here, because most of you, no doubt, have heard those eloquent remarks in that splendid speech of Sir Edward Reed only a night or two ago, when he was proposing the health of Lord Hopetoun at the banquet where we all were. It is therefore quite unnecessary for me to say anything more in expatiating upon his many qualities and his merits for the office which he honours us by filling, and I would merely submit that we return him our most sincere thanks, and express our great gratification to him for the very excellent and courteous manner in which he, at all times, presides over the meetings of this Institution.

Mr. J. MACFARLANE GRAY (Member of Council): As Mr. Martell has so well said, the eloquent speech of Sir Edward Reed at the dinner leaves me nothing to say except to cordially join in and second the vote of thanks, and also to agree with what has been said with regard to the noble urbanity of Lord Hopetoun. It must be very pleasing to all of us. I second the vote of thanks.

The vote of thanks was put and carried unanimously.

Mr. W. E. SMITH (Member): Sir John Hay and Gentlemen, it has been a matter of very great pleasure to all of us to listen to the very interesting papers that our Council has provided for us to

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consider during this session. It is quite certain that they have taken very great pains to bring such useful papers before us. After the trouble they necessarily had last year in dealing with the very excellent programme we had then, and the special circumstances of last year in connection with the International meeting, there would undoubtedly have been some excuse if they had been content to rest on their oars and had done very little for us this session. When, however, one looks down the list of papers contributed by eminent resident members, and remembers also how the members of the Council have been successful in getting such interesting papers as those contributed by Captain Kriloff and Captain Jacques, who were induced by the Council to come over and place their knowledge at our disposal in the very able manner we have all witnessed, I think we cannot do otherwise than propose a very hearty vote of thanks to our Council for what they have done for us in this connection, and therefore I beg to propose that a vote of thanks be given to them for their work.

Mr. S. W. Furze Morrish (Member): Sir John Hay and Gentlemen, I rise to second the vote of thanks to the Council. The work that they do cannot be crowded into the few days we have here each year—it must go on from month to month, but the fruits of it we see during the three days we are all here together. I beg to second the vote of thanks to the Council.

The vote of thanks was put and carried unanimously.

Sir Edward Reed, K.C.B., F.R.S. (Vice-President): Sir John Hay, I can only say I acknowledge on behalf of the Council and the Vice-Presidents, who sit with it, the very hearty vote of thanks that has just been carried. Although I am not one of the best attendants at the Council meetings, being very much out of town at times, yet I do believe and find that the Council give very close attention, indeed, to the work of the Institution; and nothing that is ever suggested for its benefit, nothing that occurs to the mind of any member of the Council to suggest, is ever neglected. The Council take a lively and a very happy interest in the affairs of the Institution, and I am sure I much appreciate your kindness in acknowledging their services. We are not in the habit—you will forgive me, Sir John, for breaking away for a moment from your authority—of passing votes of thanks to the Chairman who takes the noble President's place at our meetings, but I think I should be wanting to the Meeting if I did not give them an opportunity of showing their appreciation of his services with us to-night. (Cheers.) In saying that, and in eliciting that cheer, I should like to add to it the circumstance that in the person of our Chairman of to-night we have a man who, from the very first, brought a vast accession of influence to our Council. He joined our Institution at a very early stage; he worked for it, and served it ardently for a good many years, and he still continues to do so, and I should like him to understand with what real pleasure and satisfaction we hail his presence at every meeting, either of the Council, or of the Institution. I am told by the Secretary that this is the last speech, if I may so call it. I think I should be wanting also to you, occupying this stand for the last moment of the Meeting—I shall not propose a formal vote of thanks, because I think it is not usual, and I do not wish to put the modesty of our Secretary to any severe test—if I did not recognise, before we separate, the great value of his work, not only at these meetings, but on all occasions besides. He knows quite well what our feeling is about him. He has had marks of our very warm appreciation, and he has expressed his sympathy with us, and his gratitude for those marks of regard, but I think we ought not to separate without making him feel that he is going home to-night with the gratitude of the whole of the Institution for the work and services which he has rendered us.

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The CHAIRMAN (Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): On my own behalf, first of all, I have to thank Sir Edward Reed for the kind words he has spoken of me as your temporary chairman. When I am ordered to come here and do my duty, I do my best, and it has always given me, for more than thirty years, very great pleasure to be permitted to be associated with this learned body, considering how very little I know about the matters concerned. In expressing my gratitude to you for conferring this honour upon me, I think I must take up Sir Edward Reed's speech, and put to the meeting a vote of thanks to my friend, Mr. Holmes. He is a paragon of secretaries, and I do not believe the Council would do their duty if it were not for Mr. Holmes; he looks after us, and keeps us up to the collar, and he—unlike myself—knows all about it, which is a very great satisfaction to all of us on the Council. I believe the success of this Institution has been due as much to Mr. Holmes as to the Council, with all the learned gentlemen on the Council, and, indeed, if there were not so many of the Council present, I should say even more so; therefore I ask you to give a very hearty vote of thanks to Mr. Holmes, and I hope he may enjoy the holiday he has so well earned.

The SECRETARY (Mr. George Holmes): I thank you very much indeed, Sir John Hay and Sir Edward Reed, for your kind words. After the most magnificent proof you gave to me last Wednesday of your goodwill it is very difficult indeed to find words in which to adequately express my gratitude. All I can say is I will endeavour to deserve your approval in the future, as you have been pleased to say I have done in the past. In saying that, I know that I shall be most zealously backed up by the very devoted and efficient staff behind me.

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OBITUARY NOTICES.

Admiral Popoff, Imperial Russian Navy, Honorary Member.

(*For Portrait of Admiral Popoff see Frontispiece.*)

The Council much regrets to record the death of Admiral Popoff at St. Petersburg, on March 18 last, at the age of seventy-six. His name was well known in this country, and he counted many intimate friends among the Members and Associates of this Institution, of which he was elected an Hon. Associate in the year 1880, and on the abolition of this class he was elected an Hon. Member.

One of the earliest incidents in Admiral Popoff's career in connection with Naval architecture was the design in the year 1869 of the Russian ironclad *Peter the Great*, of a type similar to H.M.S.S. *Devastation*, *Thunderer*, and *Dreadnought;* all four of these ships were described in a paper read before the Institution in 1873 by Mr. (now Sir Nathaniel) Barnaby. He subsequently designed the two circular ironclads described in Colonel E. E. Goulaeff's paper, read before the Institution in 1876. It was also due to Admiral Popoff that the Nicolaieff Floating and Depositing Dock on Messrs. Clark & Standfield's system was built for the use of the Russian Black Sea fleet. This dock is described in a paper read by Mr. Latimer Clark, and published in Vol. XVII. of the Transactions, and also in a paper by Colonel Goulaeff published in Vol. XIX. This dock has the great advantage that vessels of great breadth, such as the circular ironclads, can be deposited on and lifted by it with ease.

Admiral Popoff's two fundamental principles in the design of vessels were to increase their breadth and displacement. He was wont to insist upon the dogma that the power of warships is their displacement. In applying this principle in the Russian Navy he rose, at one bound, from the displacements of 4,000 to 5,000 tons of the earlier Russian ironclads to 10,000 tons in the *Peter the Great*, which was designed in the year 1869 at a time when he was much hampered by the smallness of the Russian Navy estimates.

His steady adherence to the principle of broadening vessels led him, after the construction and trial of the two circular ironclads, to the design, ten years later, of the famous Imperial yacht *Livadia*, which was built from Admiral Popoff's design by

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Messrs. John Elder & Co. for the late Emperor Alexander II. Notwithstanding her beam of 153 ft. this vessel obtained a speed, on her trials on the Clyde, of 17 knots.

Admiral Popoff designed in the year 1881 an ironclad for the Russian Navy on the general lines of the *Livadia*. This vessel was intended to have a length of 250 ft.; breadth of 177 ft., and a draught of 13 ft. 6 in., and was to have carried eight 12 in. guns on a displacement of 11,250 tons. Owing to the death of the Emperor Alexander and the serious illness and subsequent death of the Grand Duke Constantine, this design was never carried into execution.

Admiral Popoff claimed the following advantages for his broad ships:—Firstly, the possibility, owing to the increased interior space, of surrounding the vitals of the ship by double circumferential water-tight bulkheads, forming, together with the outside skin, double rows of side compartments, which he considered conferred practical immunity from the effects of torpedo and ram attack. Secondly, he claimed for this type great stability and steadiness at sea, with the attendant advantage of making excellent gun platforms. Thirdly, as such vessels admit of being constructed on a very small draught, compared with ships of ordinary form, he claimed that they possessed considerable advantages for shallow waters.

It should here be mentioned that the *Livadia* was provided with three screw propellers worked by independent engines, and that she was the first large vessel thus fitted. The circular ironclads were provided with a still greater number of propellers, and on board one of them Admiral Popoff introduced a method of steering direct from the bridge, by running either of the side engines and propellers at a faster rate than the remainder.

Admiral Popoff designed, as far back as 1869, two belted cruisers for the Russian Navy, the *General Admiral* and the *Duke of Edinburgh*, of about 4,600 tons and protected by a complete armour-belt along the water-line. These vessels may be considered as the prototypes of the modern class of belted cruiser.

Mr. James B. C. Crossland.

Mr. Crossland was for many years a Member of the Institution, though he had retired from it, on account of ill-health, some years before his death. He was not widely known, but, at the Admiralty, where he was one of the chief constructors, and at the Royal School of Naval Architecture, where he was the technical instructor in 1866 and subsequently, he was held in the highest honour. As has been said of Professor Clerk Maxwell, he never seemed to think wrong in matters of natural science.

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He was constantly appealed to by his colleagues in matters of difficulty. He had no ambition and no eagerness of nature, so that nothing remarkable can be set down to his initiative; but he was invaluable for detecting errors and fallacies. His keen thought seemed to cleave at once through the perplexities of the problems presented to him.

Mr. Crossland was born at Portsmouth, May 19, 1831; he served an apprenticeship as a shipwright in the Royal Dockyard at Deptford. In 1849 he was sent by the Admiralty to the Royal School of Mathematics and Naval Construction in Portsmouth Dockyard, where Dr. Joseph Woolley was the principal. In the year 1855 he entered the designing office at the Admiralty as a draughtsman. On July 19, 1864, he was appointed Assistant Constructor of the Navy, the Chief Constructor being Sir Edward Reed, then Mr. Reed. He remained at the Admiralty as a Chief Constructor until October 1, 1881, when, on account of infirm health, he retired. Subsequently to his retirement he was unable to take any active part in professional or other matters. He died on February 27, 1897. His mind retained its full vigour until the last, but there was partial paralysis which, for some years before he died, made it difficult for him even to sign his name.

Mr. Crossland read two valuable papers before the Institution, entitled, "On Mr. Froude's Theory of Rolling"—published in Vol. III. of the "Transactions—and "On some Deductions from the Trials of Screw Steamships," which appeared in Vol. V. He was elected a Member of Council in the year 1865, and continued to hold that position till the year 1881.

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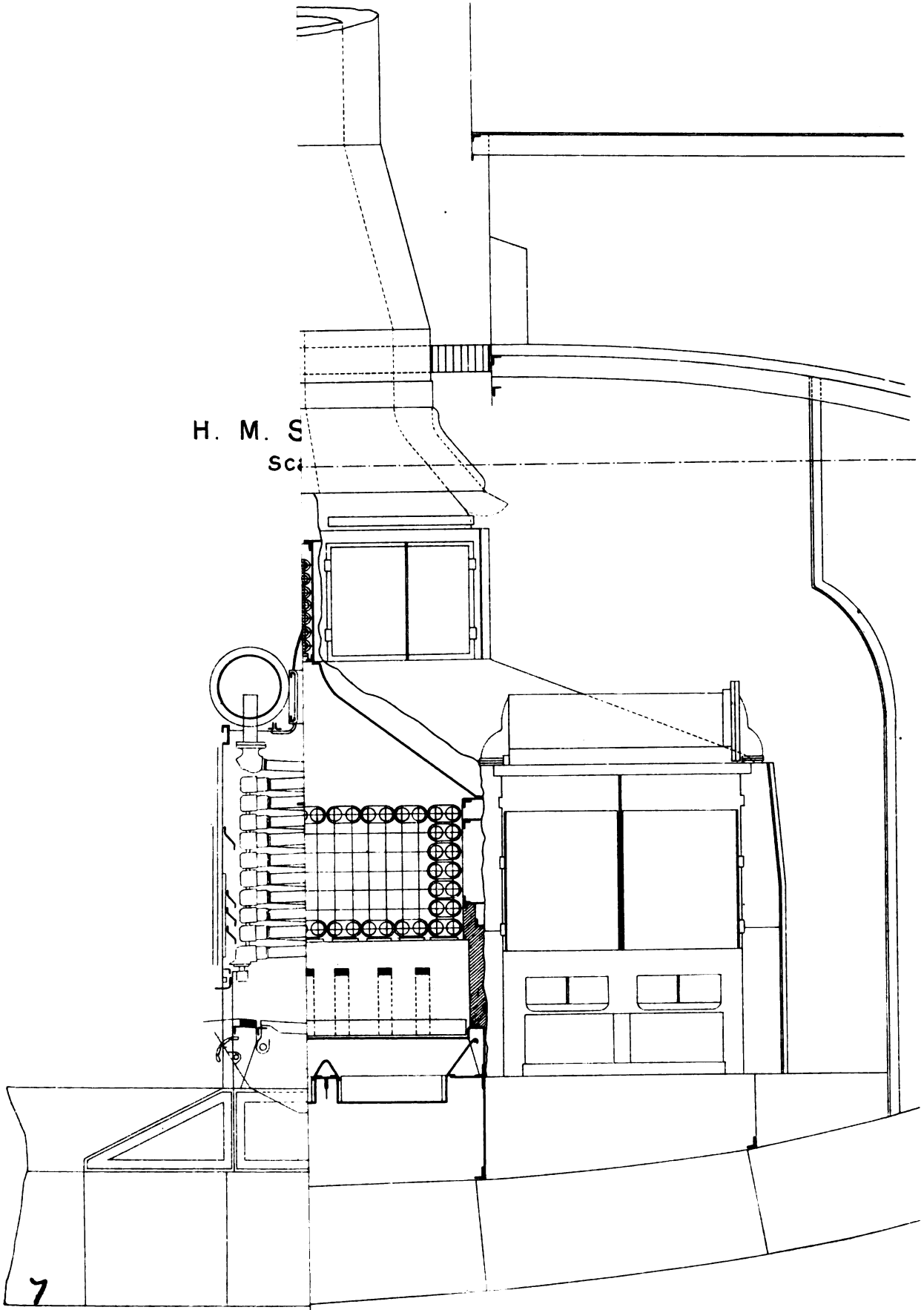

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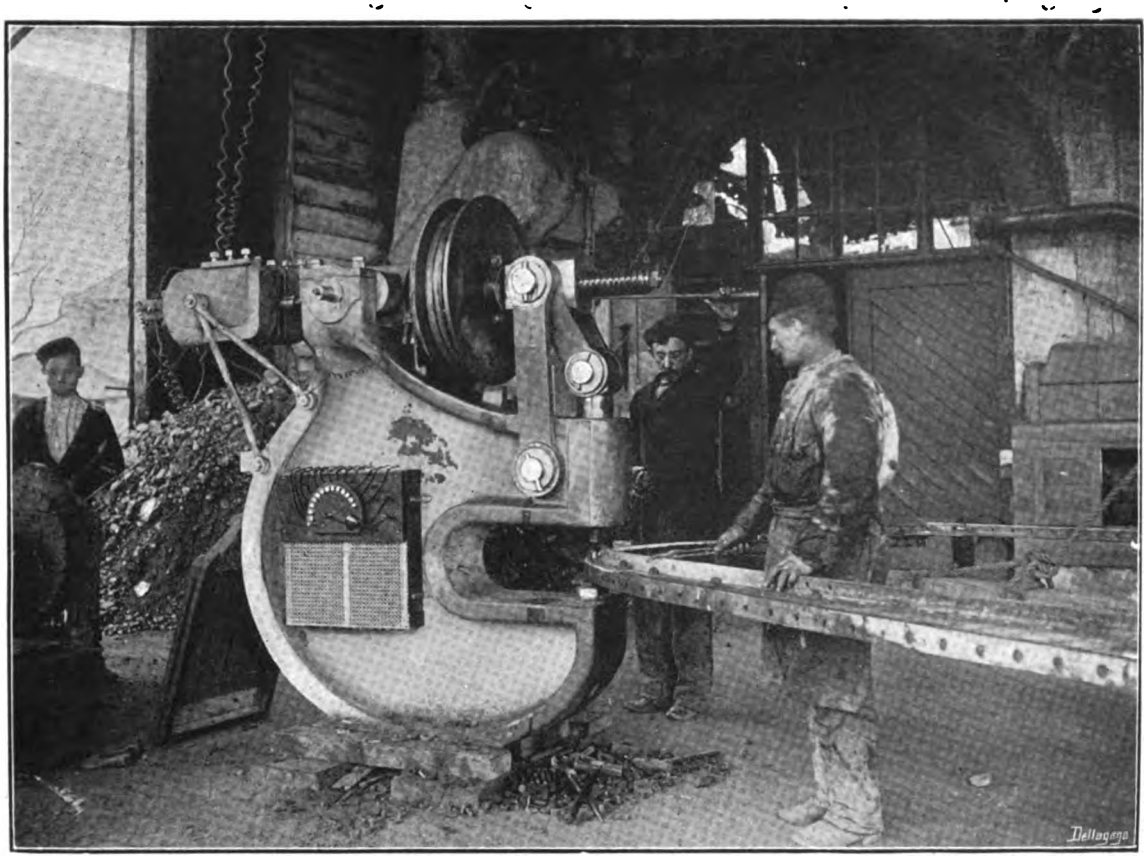

Fig. 1.

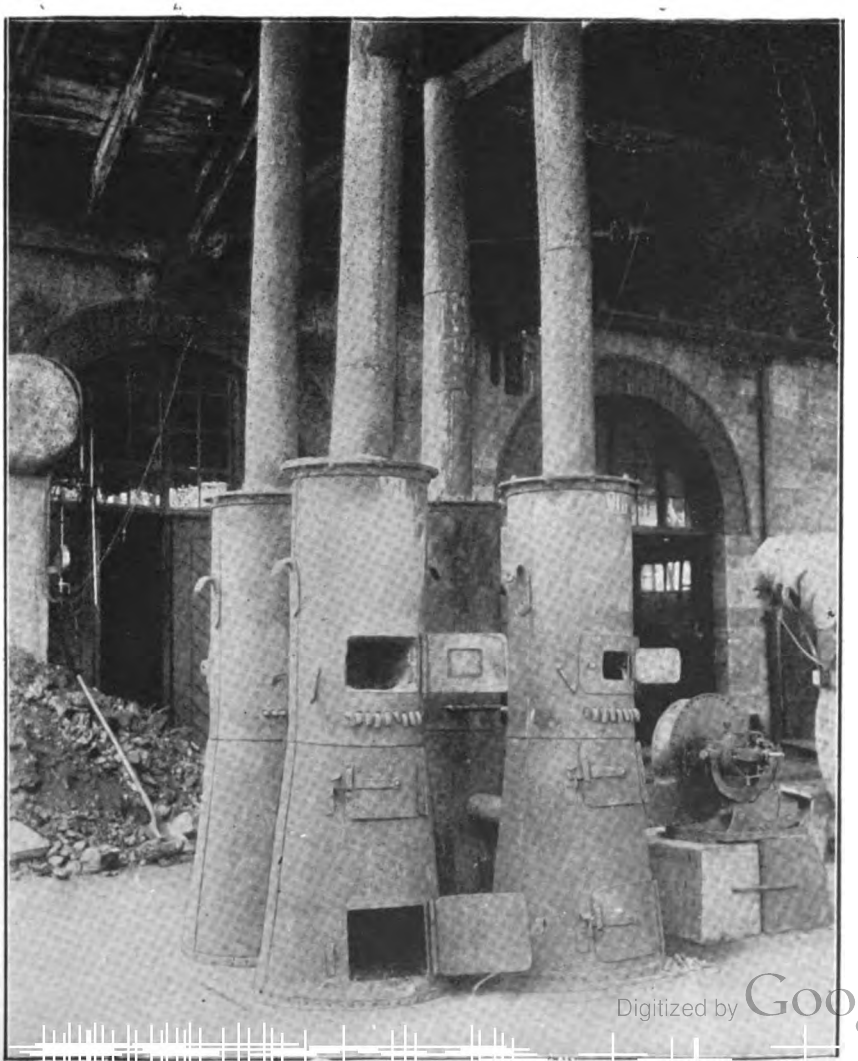

Fig. 2.

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THE ARROWS DENOTE DIRECTION OF FLOWING WATER.

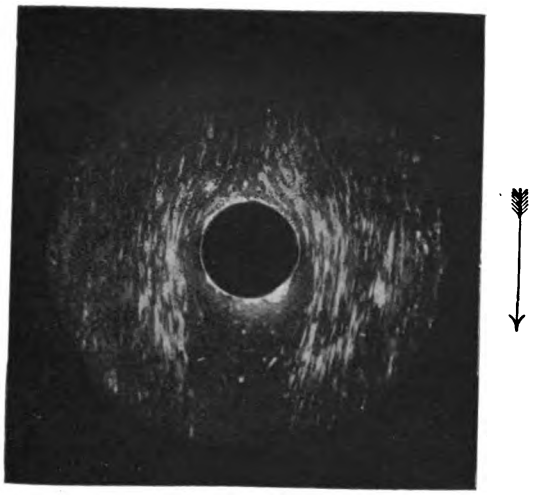

Fig. 1.
SMOOTH CYLINDER IN CLEAR WATER.

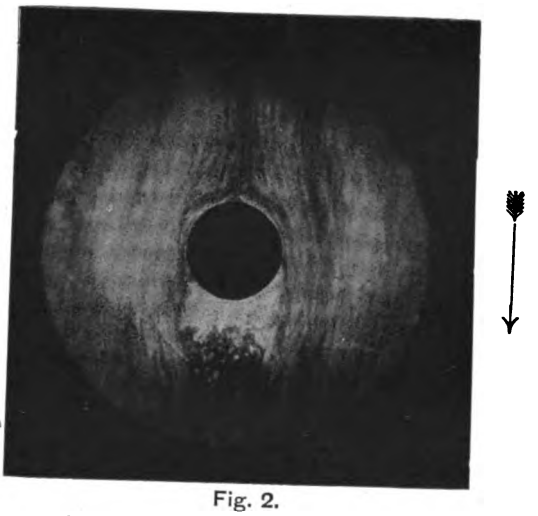

Fig. 2.
SMOOTH CYLINDER IN SOAPY WATER.

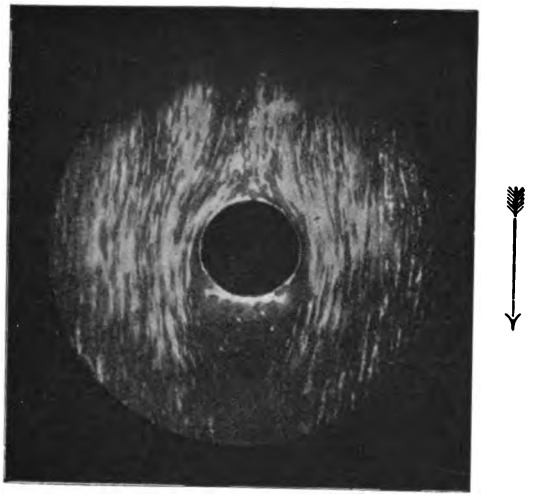

Fig. 3.
ROUGH CYLINDER IN CLEAR WATER.

Fig. 4.
ROUGH CYLINDER IN SOAPY WATER.

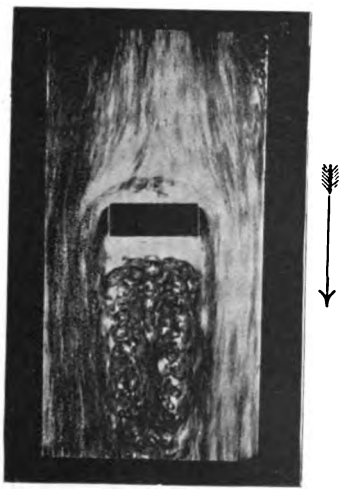

Fig. 5.
CLEAR WATER.

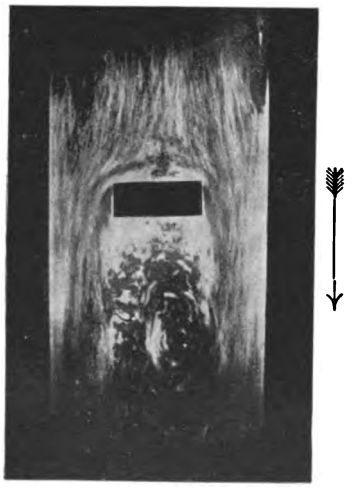

Fig. 6.
SOAPY WATER.

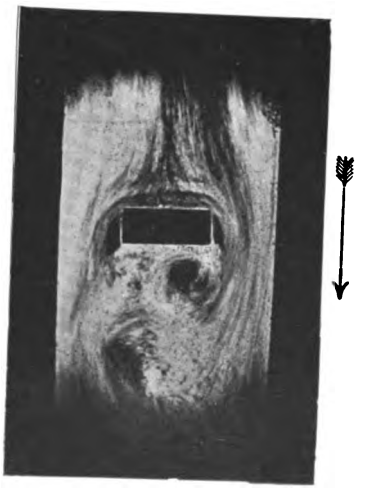

Fig. 7.
SOAPY WATER WITH OSCILLATION OF WAKE.

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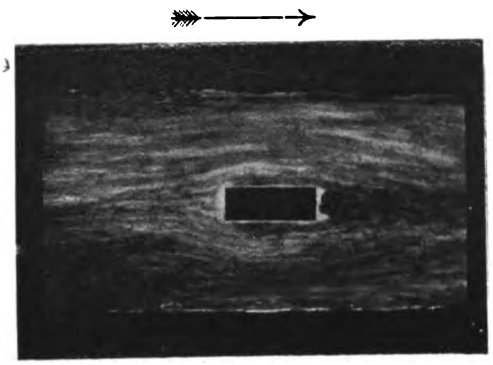

Fig. 8.

CLEAR WATER.

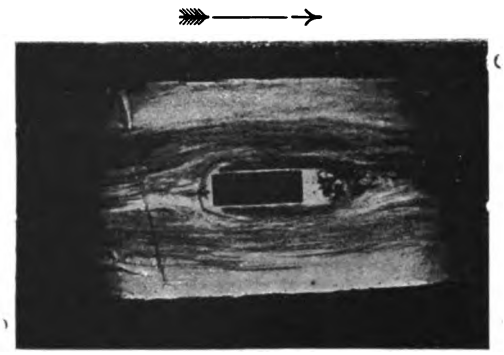

Fig. 9.

SOAPY WATER.

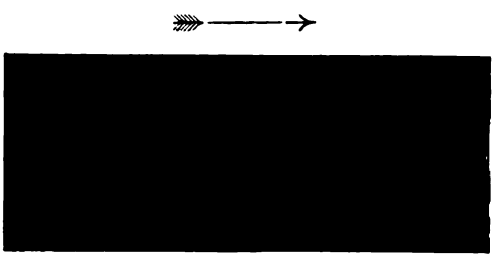

Fig. 10.

UPPER SIDE PARAFFIN.
LOWER SIDE SMOOTH LEAD.

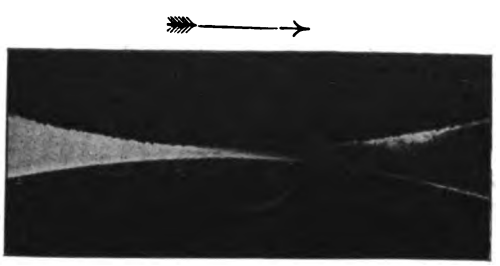

Fig. 11.

UPPER SIDE ROUGH SAND.
LOWER SIDE SMOOTH LEAD.

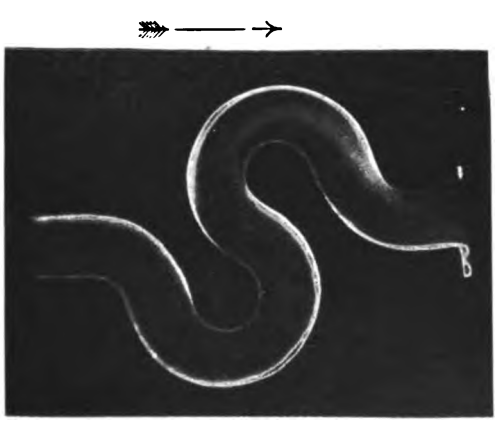

Fig. 12.

CLEAR WATER WITH MUCH AIR.

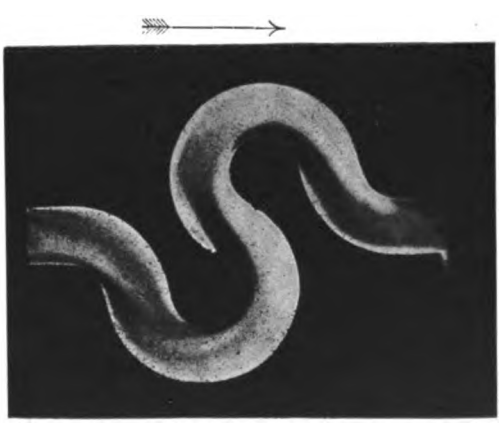

Fig. 13.

CLEAR WATER WITH LITTLE AIR.

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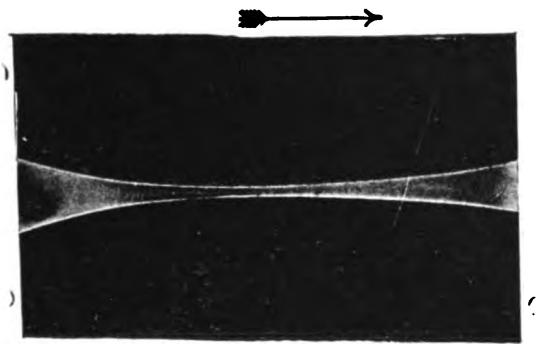

Fig. 14.

NARROW PASSAGE SHOWING THIN CLEAR FILM.

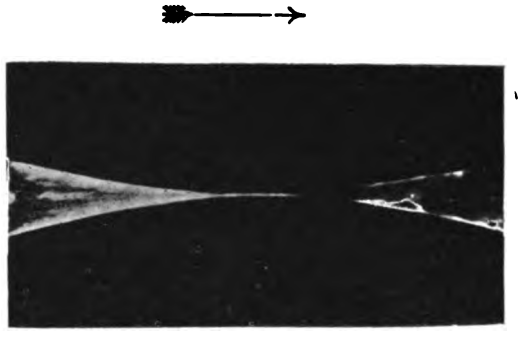

Fig. 15.

PASSAGE STILL FURTHER REDUCED, SHOWING FAILURE OF AIR METHOD.

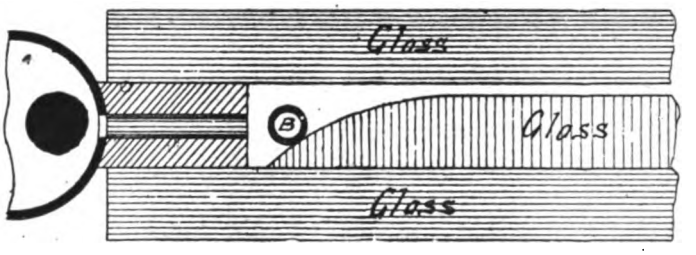

Fig. 16.

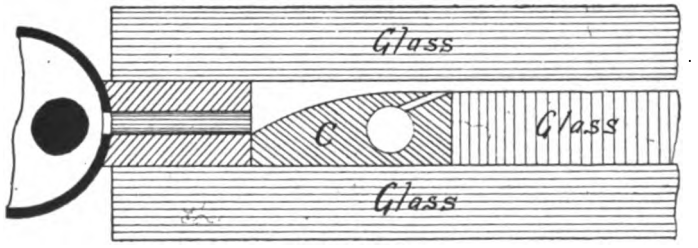

Fig. 17.

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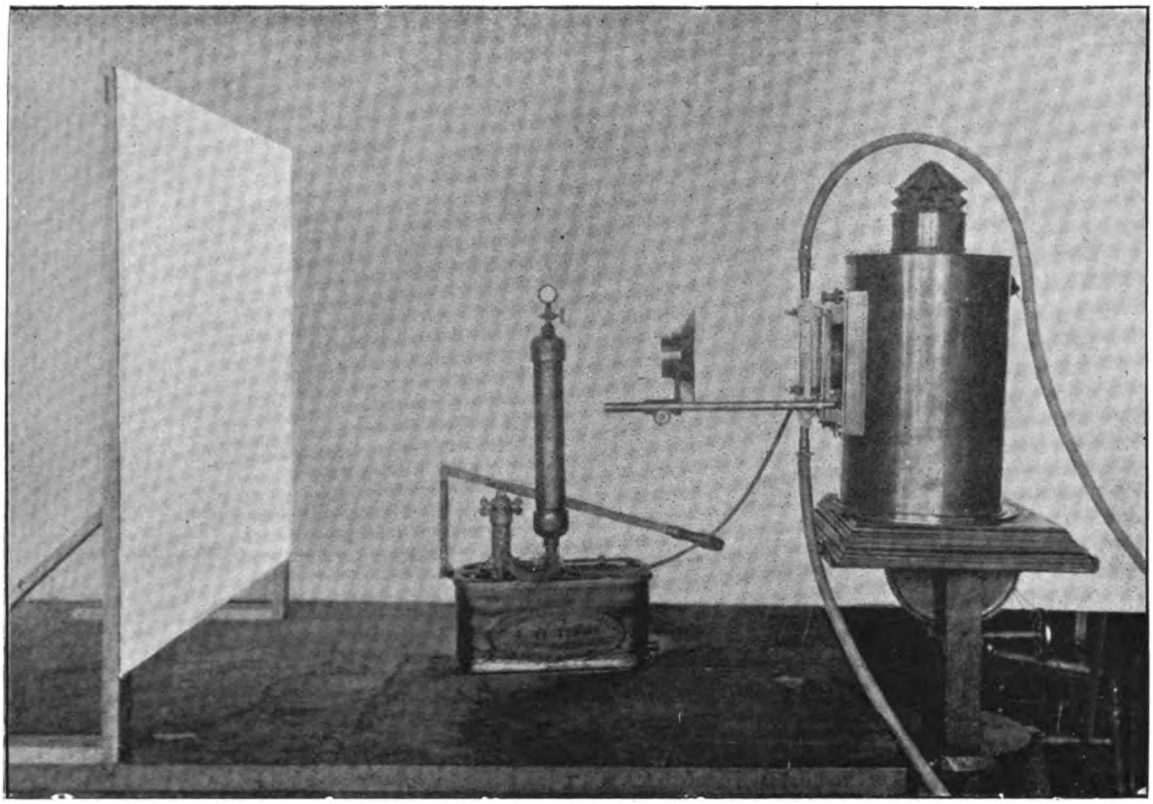

Fig. 18.
ARRANGEMENT OF APPARATUS FOR PROJECTING RESULTS ON SCREEN.

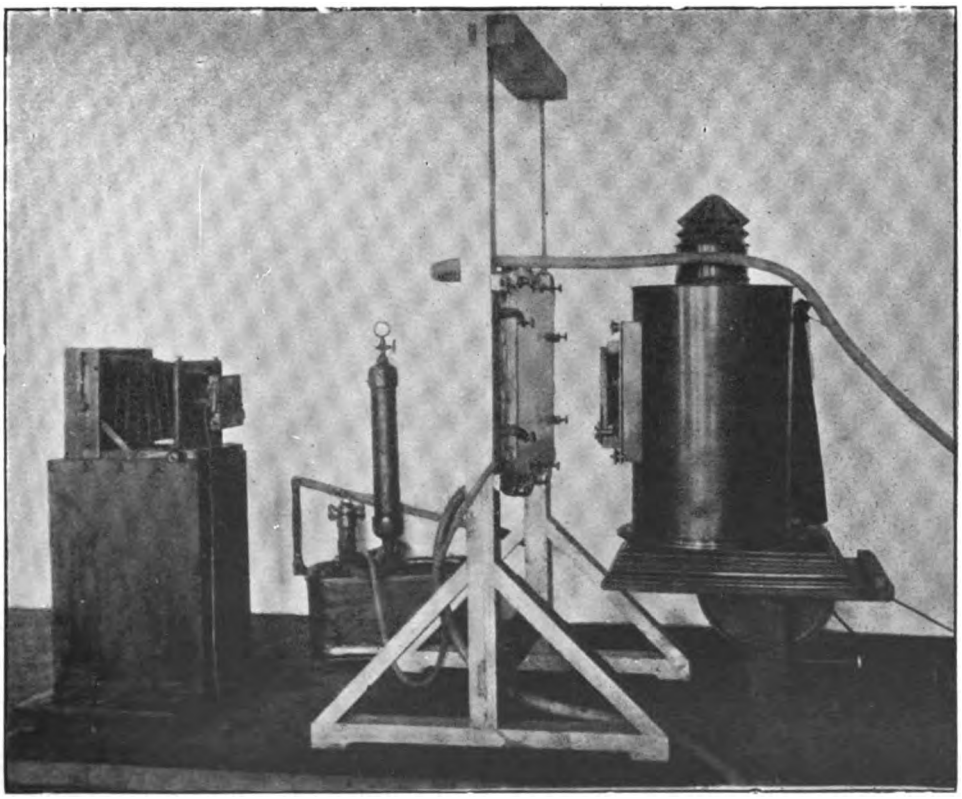

Fig. 19.
APPARATUS ARRANGED FOR PHOTOGRAPHING RESULTS.

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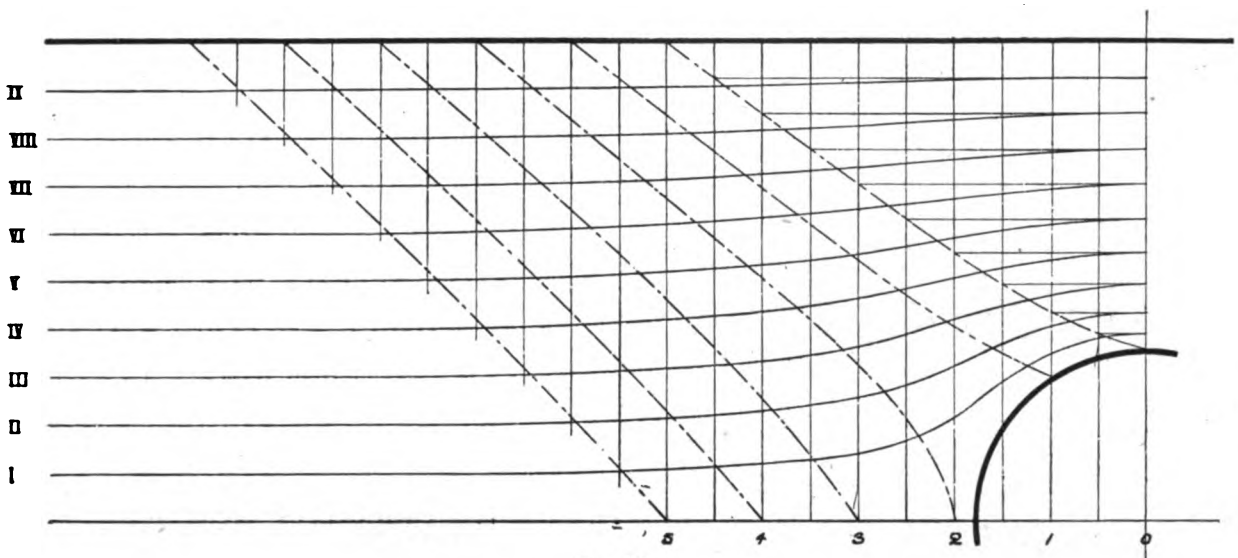

Fig. 20.

DIAGRAM FOR TEST CASE (SEE APPENDIX).

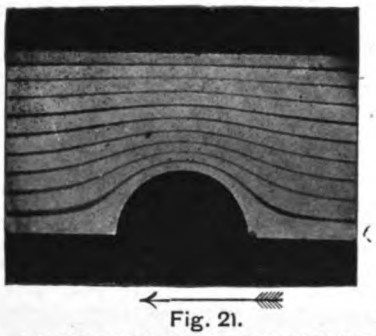

Fig. 21.

ACTUAL STREAM BANDS IN TEST CASE.

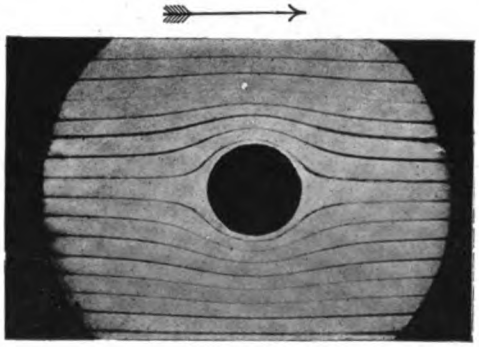

Fig. 22.

CYLINDER ON CHANNEL (SIDES CORRESPONDING TO LINES IN FIG. 23).

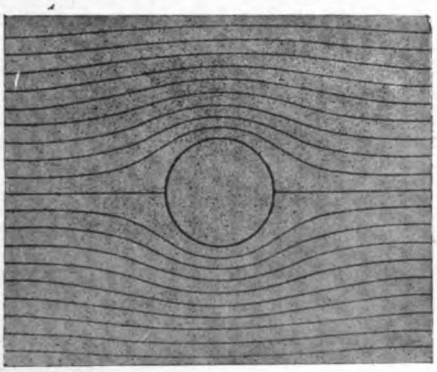

Fig. 23.

CYLINDER IN INFINITE FLUID.

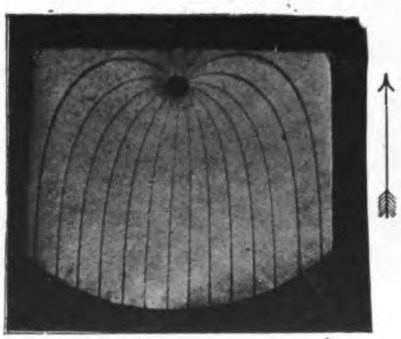

Fig. 24.

UNIFORM STREAM AND "SINK" IN CHANNEL.

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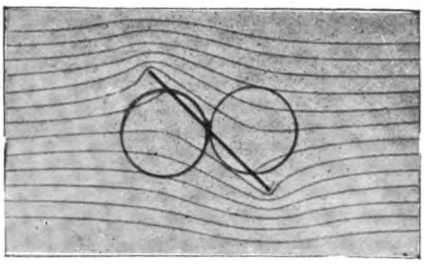

Fig. 25.

LAMB'S DIAGRAM FOR PLATE AT 45 DEGREES, WITH TEST CIRCLES.

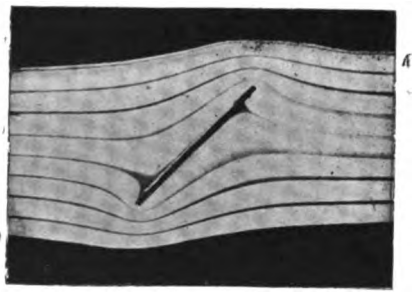

Fig. 26.

ACTUAL COLOUR BANDS (NARROW).

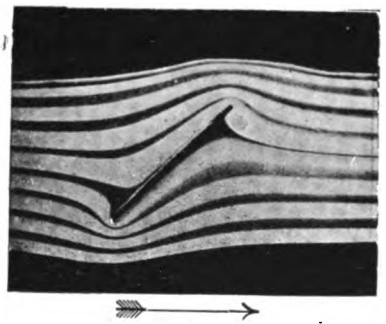

Fig. 27.

ACTUAL COLOUR BANDS (BROAD).

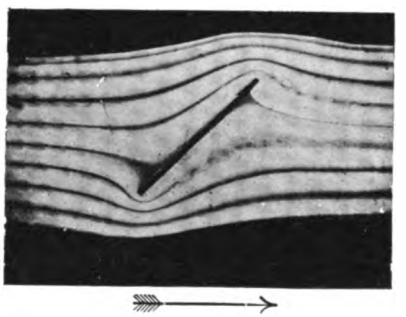

Fig. 28.

RESULT OF VIBRATION.

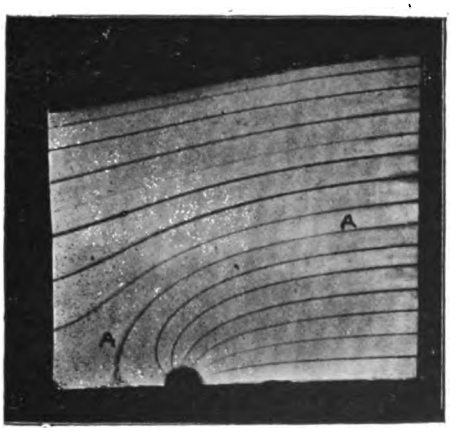

Fig. 29.

UNIFORM STREAM AND "SINK"

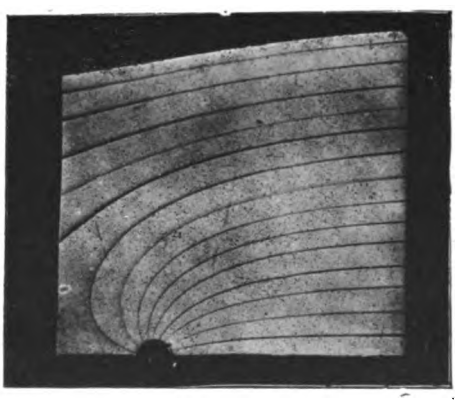

Fig. 30.

UNIFORM STREAM AND "SINK."

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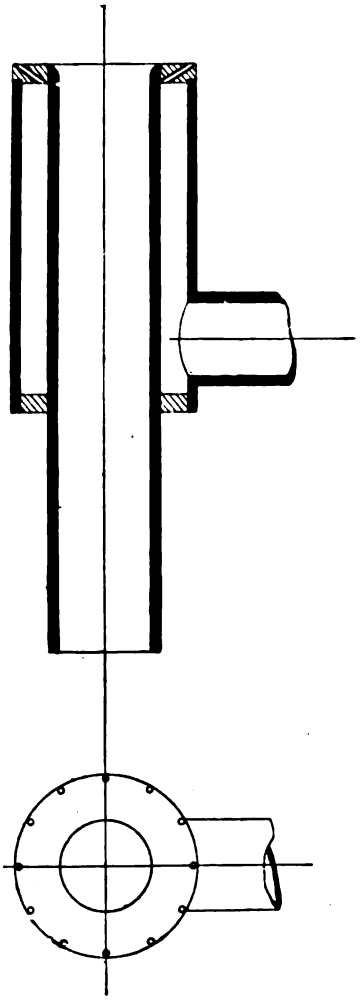

Fig. 31
ARTIFICIAL SOURCE.

Fig. 32.
EQUAL "SINK" AND "SOURCE."

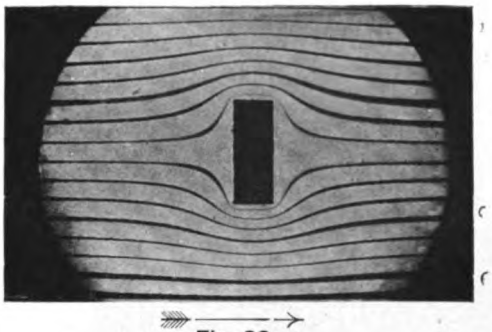

Fig. 33.
RECTANGULAR BODY (BROADSIDE).

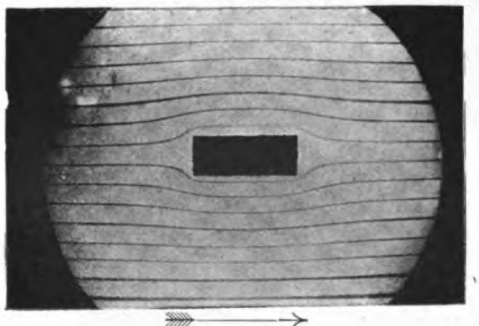

Fig. 34.
RECTANGULAR BODY (ENDWAYS).

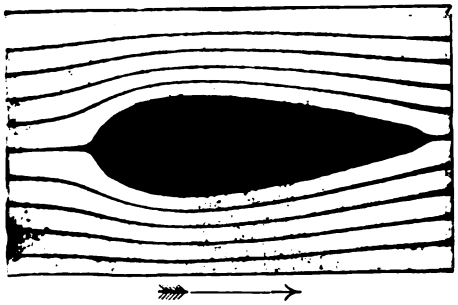

Fig. 35.
AS USED.

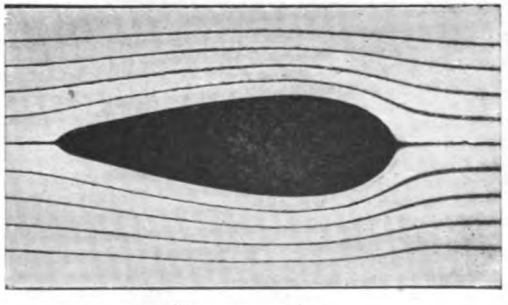

Fig. 36.
REVERSED.

SCREW SHAFT STRUT (NARROW COLOUR BANDS IN THIN SHEET).

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Trans. Inst. Naval Architects, Vol. XL., 1898.

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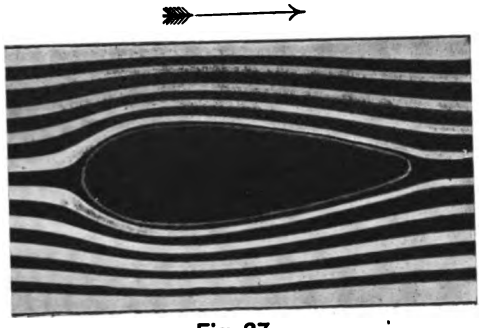

Fig. 37.

AS USED.

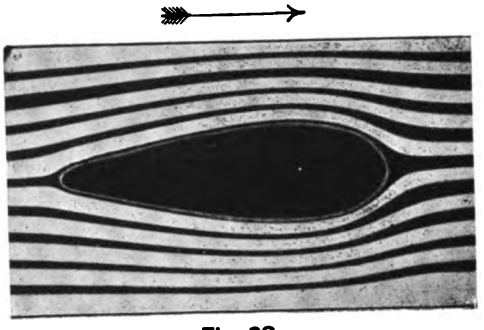

Fig. 38.

REVERSED

SCREW SHAFT STRUT (BROAD COLOUR BANDS IN THIN SHEET).

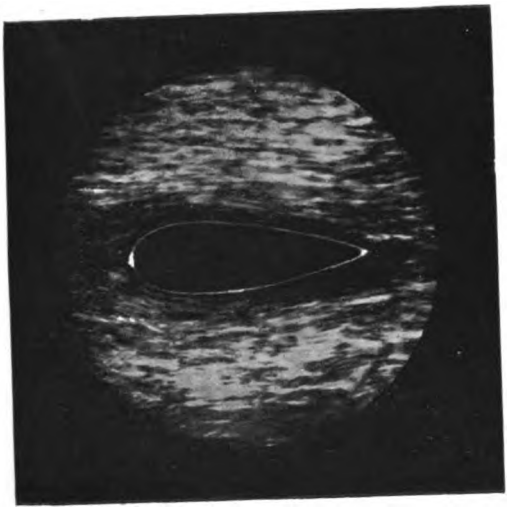

Fig. 39.

AS USED.

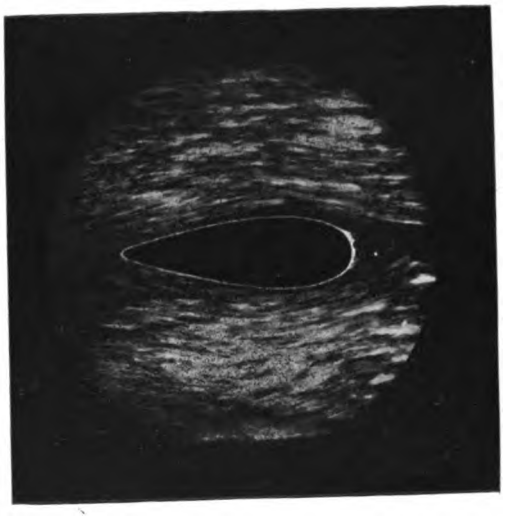

Fig. 40

REVERSED.

SCREW SHAFT STRUT (AIR METHOD IN THICK SHEET).

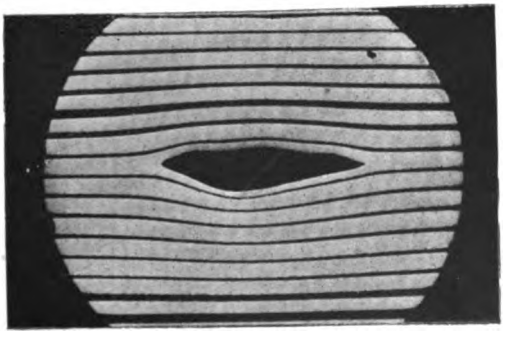

Fig. 41.

VERTICAL SECTION OF DOLPHIN.

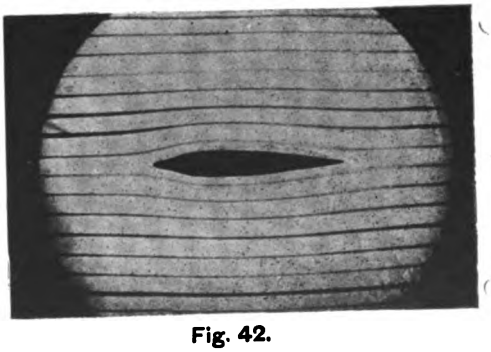

Fig. 42.

HORIZONTAL SECTION OF DOLPHIN.

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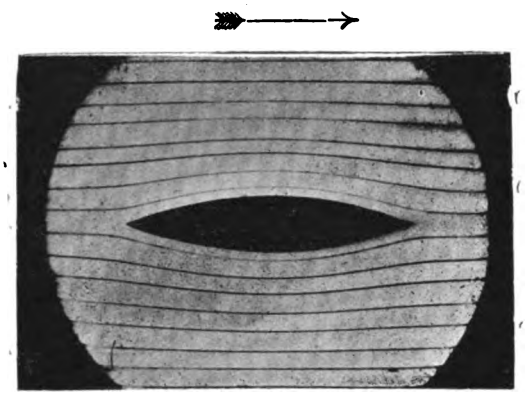

Fig. 43.

TAYLOR'S SHIP-SHAPE FORM (NARROW COLOUR BANDS).

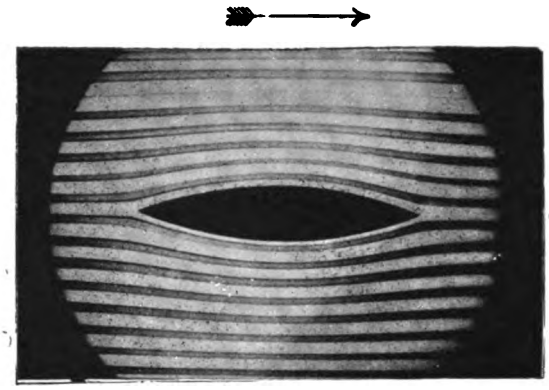

Fig. 44.

TAYLOR'S SHIP-SHAPE FORM (BROAD COLOUR BANDS)

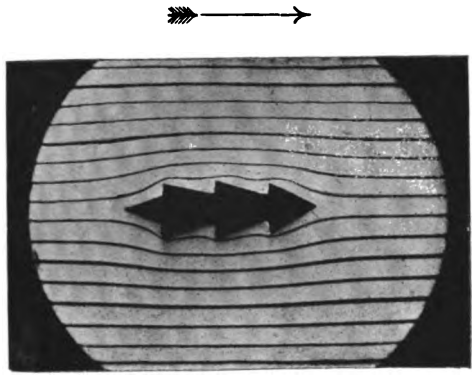

Fig. 45.

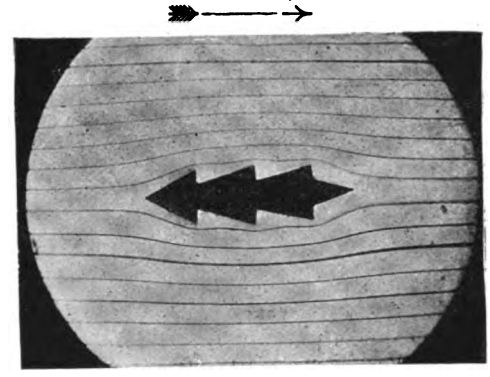

Fig. 46.

STREAM LINES FOR THIN SAW-TOOTH MODEL.

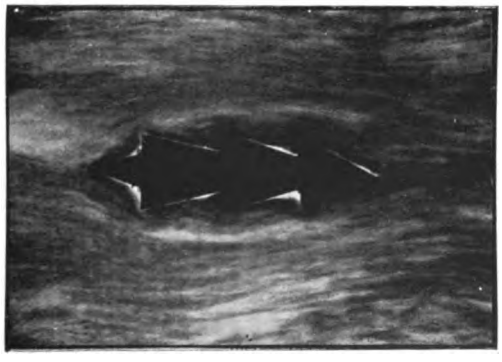

Fig. 47.

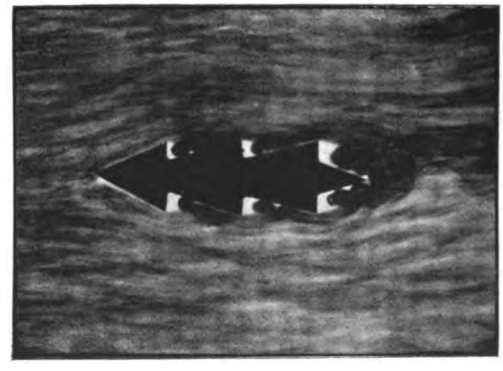

Fig. 48.

WATER FLOWING ROUND THICK SAW-TOOTH MODEL.

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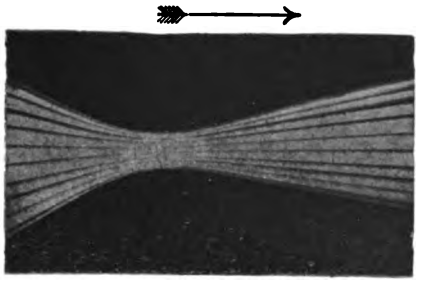

Fig. 49.

NARROWING AND ENLARGING CHANNEL.

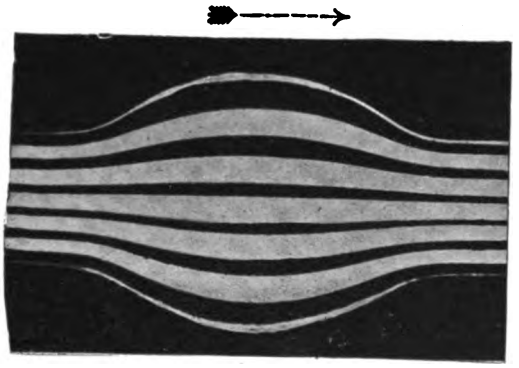

Fig. 50.

BROAD COLOUR BANDS.

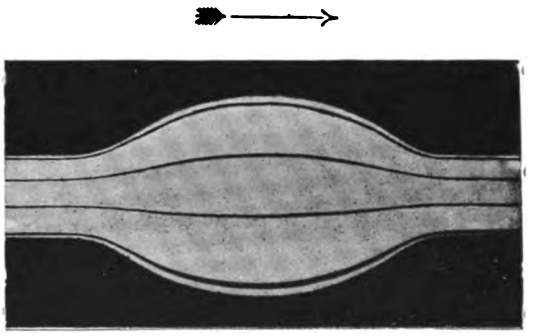

Fig. 51.

NARROW COLOUR BANDS.

GRADUALLY ENLARGING AND CONTRACTING CHANNEL.

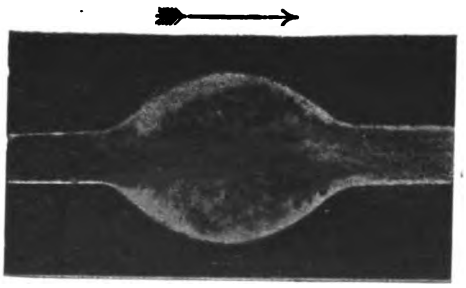

Fig. 52.

SINUOUS MOTION IN GRADUALLY ENLARGING AND CONTRACTING CHANNEL

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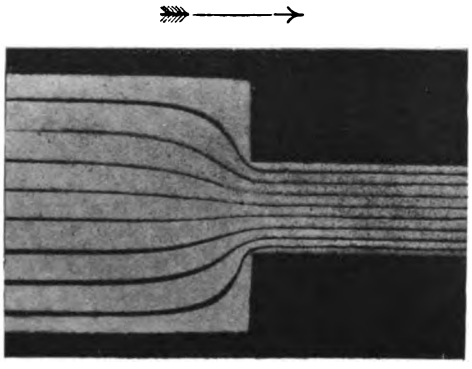

Fig. 53.

SUDDEN CONTRACTION.

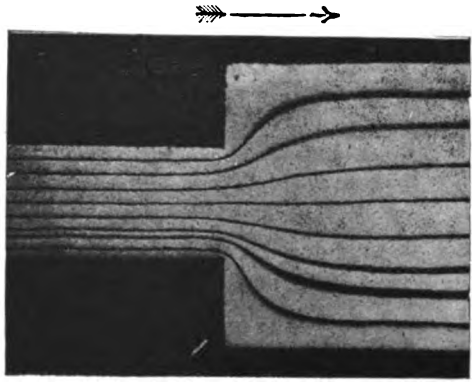

Fig. 54.

SUDDEN ENLARGEMENT

STREAM-LINE MOTION.

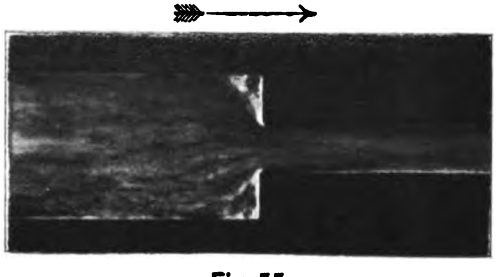

Fig. 55.

SUDDEN CONTRACTION.

Fig. 56.

SUDDEN ENLARGEMENT.

SINUOUS MOTION.

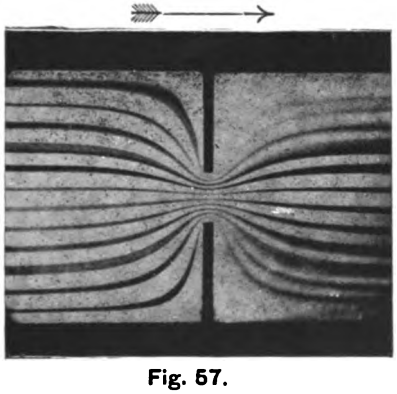

Fig. 57.

STREAM-LINE MOTION.

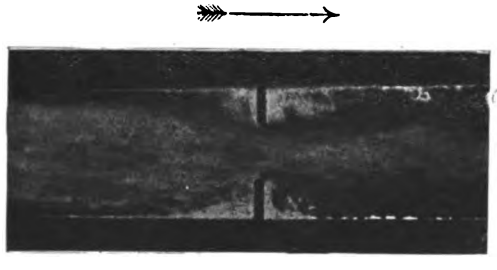

Fig. 58.

SINUOUS MOTION.

PIERCED DIAPHRAGM.

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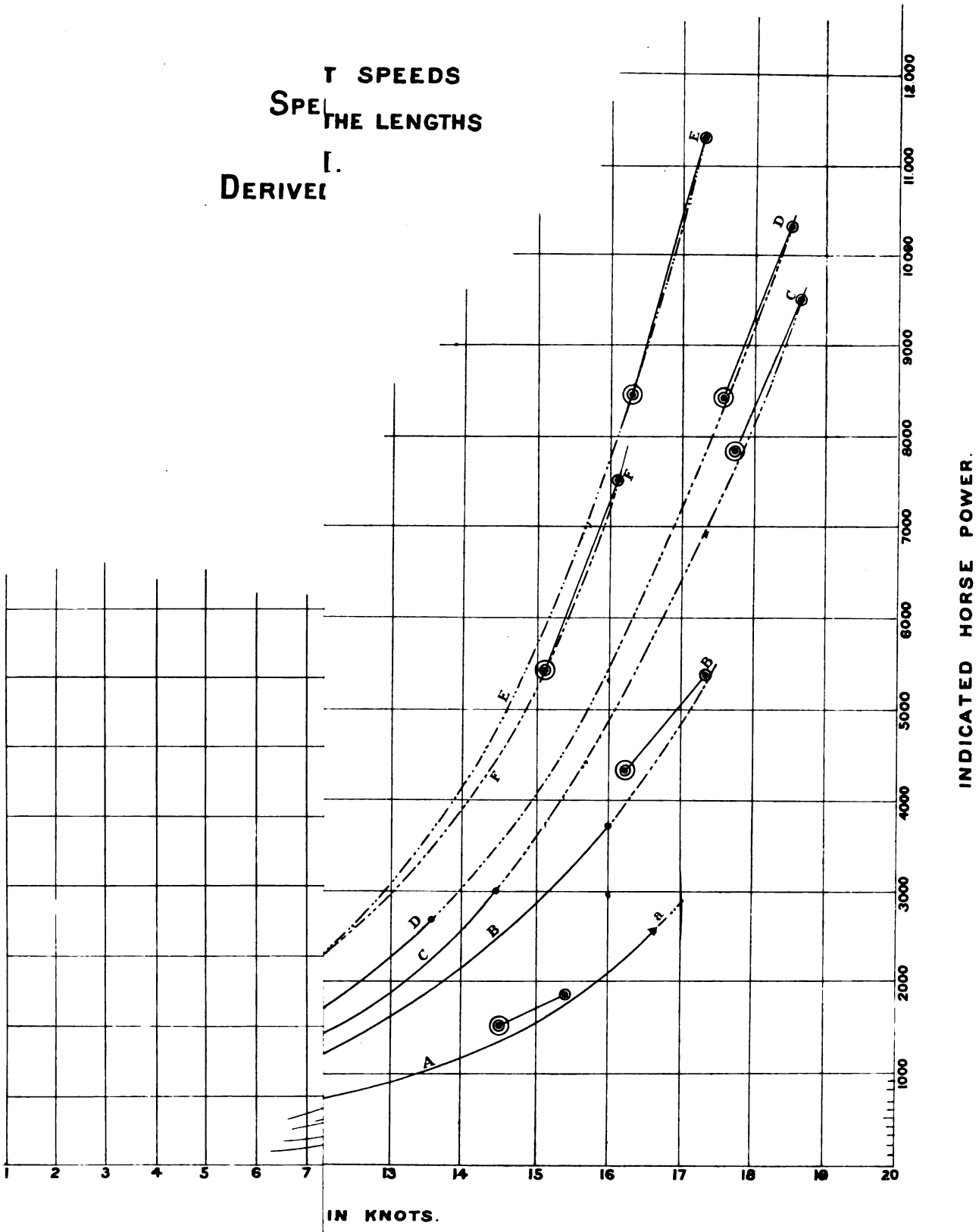

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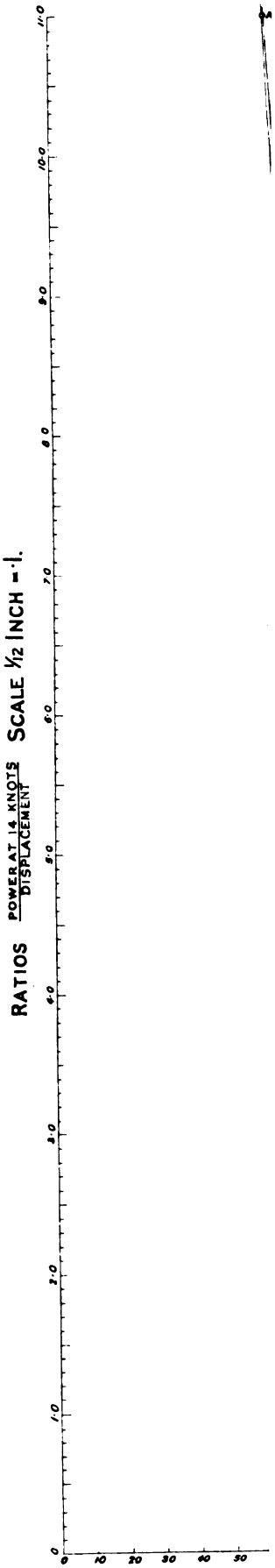

FINER AFTER BODY, BUT
AME INSTANCE APART.

SCREWS 11½ CLOSER TOGETHER
ME CLEARANCE AS IN No 4.

BOACHSHIP ATLANTIC LINER TYPE.

MAYCROFT PATTERN OF STERN.

ROFT BUILD.

BUILD.

BUILD.

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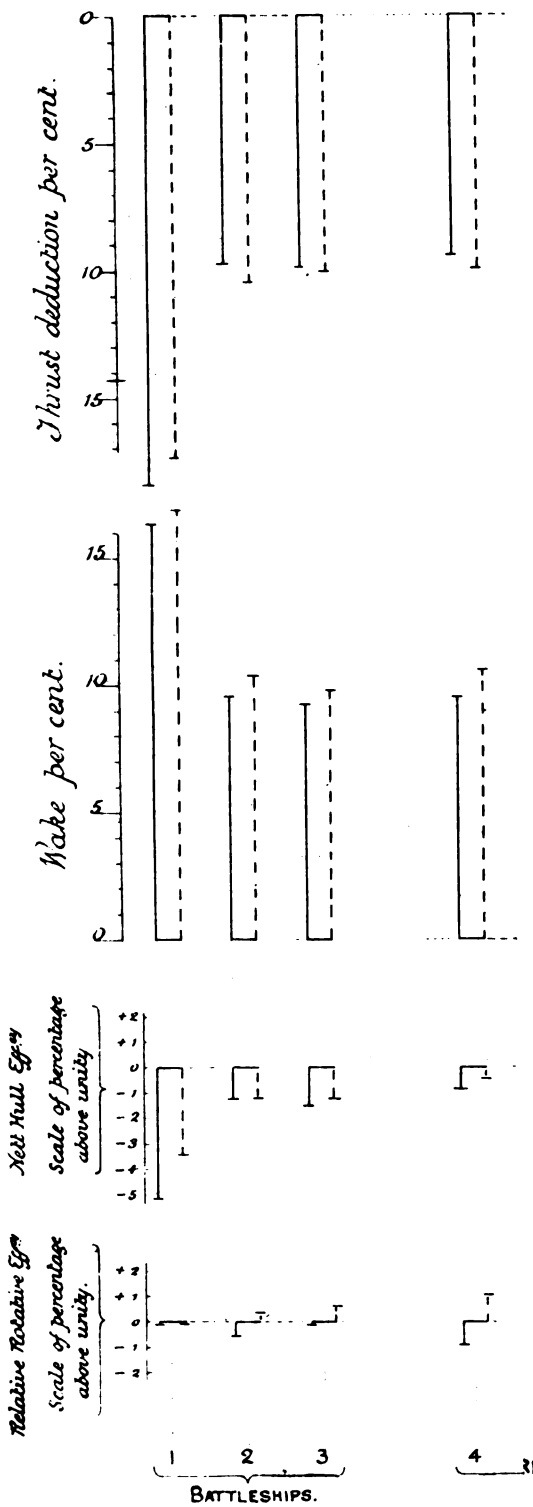

REFERENCE TABLE FOR DIAGRAM

PARTICULARS OF VESSELS INCLUDED

	Form No	* Dimension Constants Length.	Beam.	Draft.	Prismatic Coefs Fore Body	After Body	
Battleships.	1	4·85	·933	342	·638	·737	
	2	5·09	·966	·339	·600	·624	
	3	5·08	·966	·338	·618	·678	
Cruisers.	4	5·48	·975	·359	·577	·587	
	5	5·48	·975	·359	·561	·573	No 4 with finer after body, but screws same distance apart.
	6	5·48	·975	·359	·561	·573	No 5 with screws 11% closer together giving same clearance as in No 4.
	7	6·34	·888	·334	·566	·628	
	8	6·55	·840	·303	·640	·704	
	9	6·55	·852	·303	·613	·683	Lines approaching Atlantic Liner type.
	10	6·55	·852	·303	·593	·668	
	11	6·01	·951	·348	·550	·593	
	12	5·88	·952	·337	·567	·622	
	13	7·19	·863	·323	·633	·620	
	14	7·14	·868	·321	·569	·596	
	15	6·55	·859	·360	·531	·607	
Extreme shallow draft vessel.	16	4·35	1·143	·264	·577	·624	Has Thornycroft pattern of stern.
Destroyers.	17	9·81	·909	·267	·573	·540	Thornycroft build.
	18	9·67	·902	·275	·531	·581	
	19	9·66	·979	·266	·535	·605	Laird build.
	20	9·83	·983	·261	·505	·544	
	21	9·51	·907	·256	·598	·613	Palmer build.

* The figures are the actual dimensions of ship, multiplied by $\frac{\cdot 2057}{(\text{Displacement in tons})^{\frac{2}{3}}}$; they may equally be regarded as the actual dimensions of an imaginary model of the ship of one cubic foot disp.t [See Trans: I.N.A. vol XXIX, p 309, § 20, and p 312, § 28]

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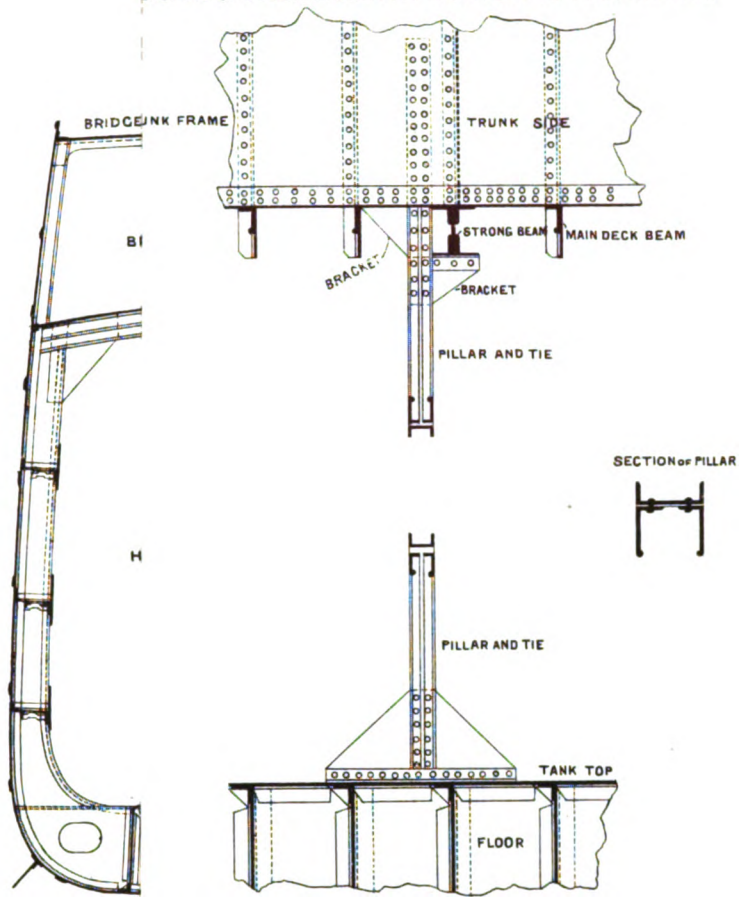
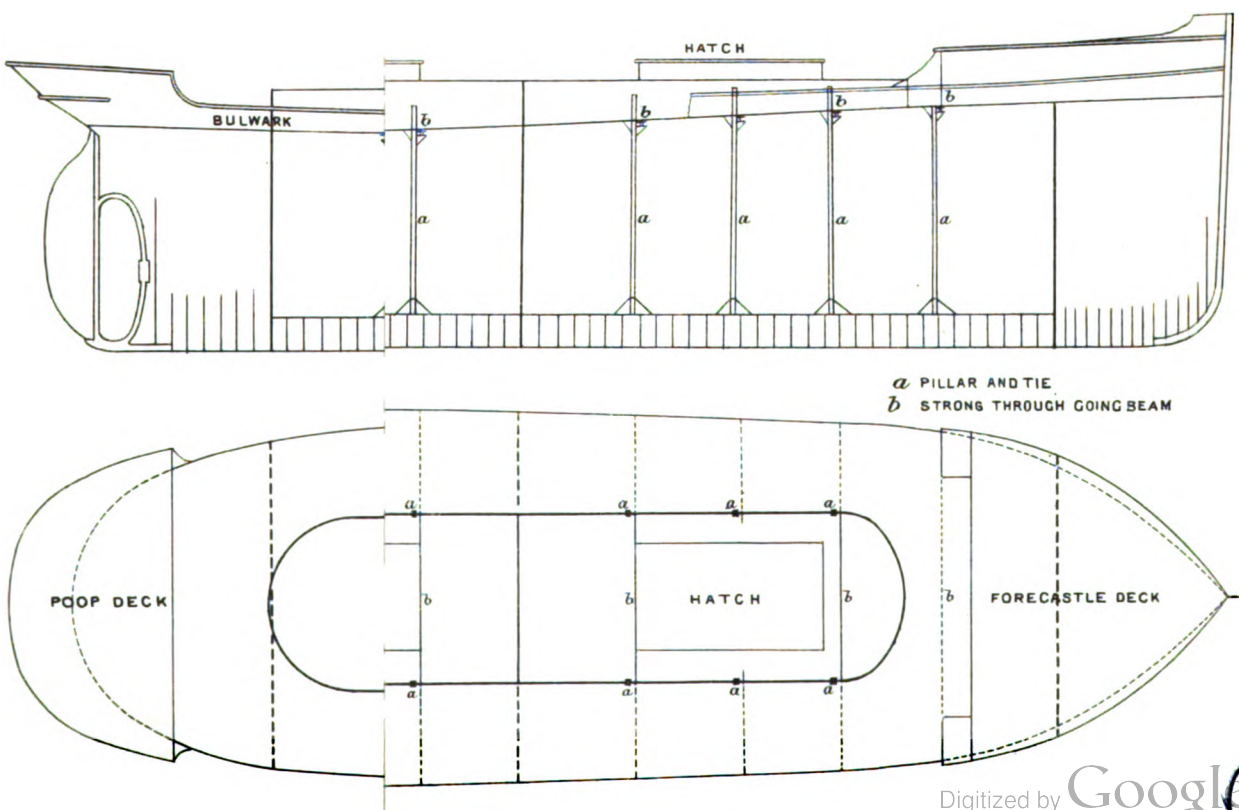
Fig. 3.

Detail of Pillaring and Attachment to Strong Beam





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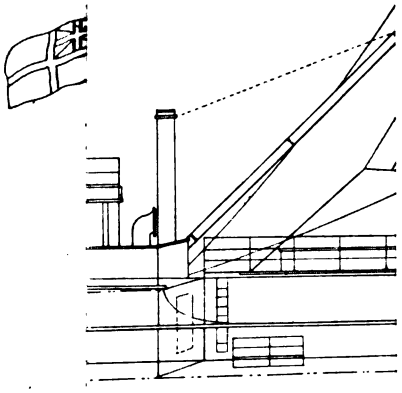

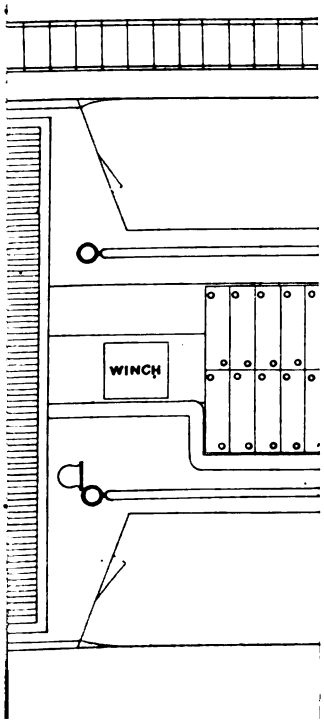

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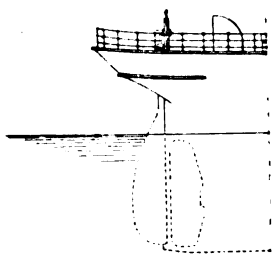

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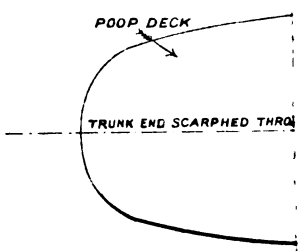

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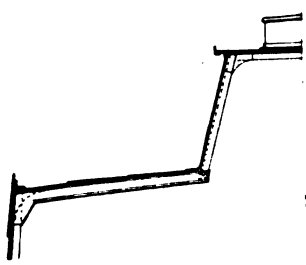

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To Illustrate Mr. B. Schieldrop's Paper on Resistance to the Motion of Solids in a Fluid.

FIG. 4.

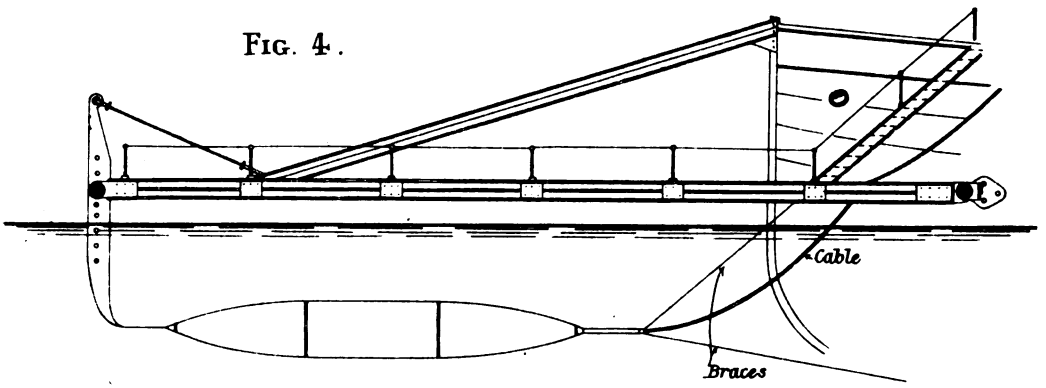


FIG. 5.

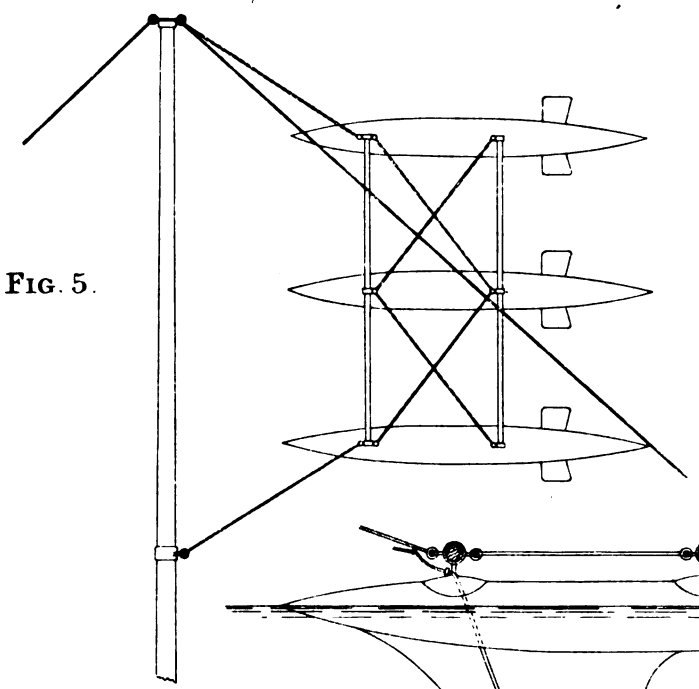
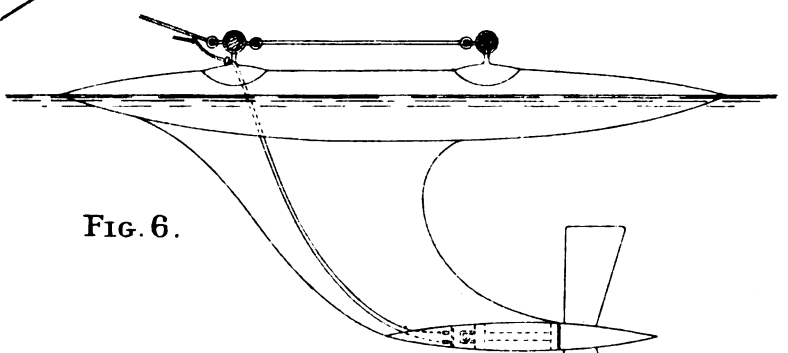


FIG. 6.



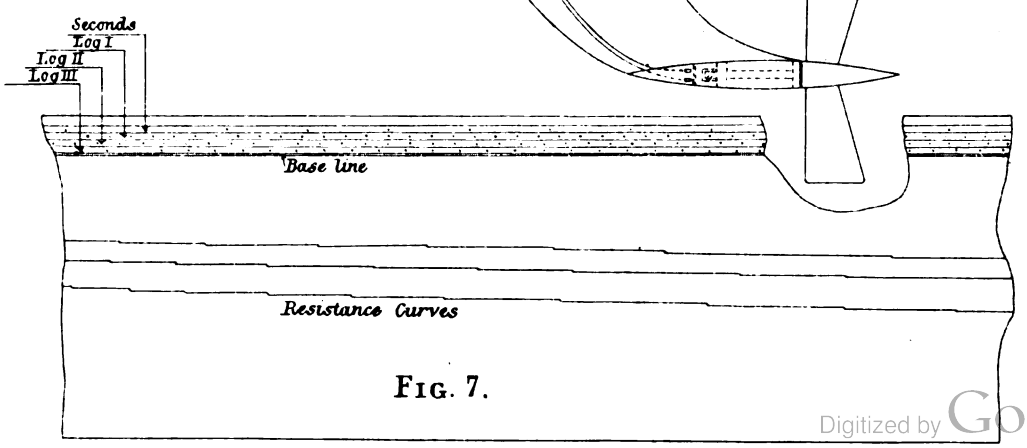


FIG. 7.

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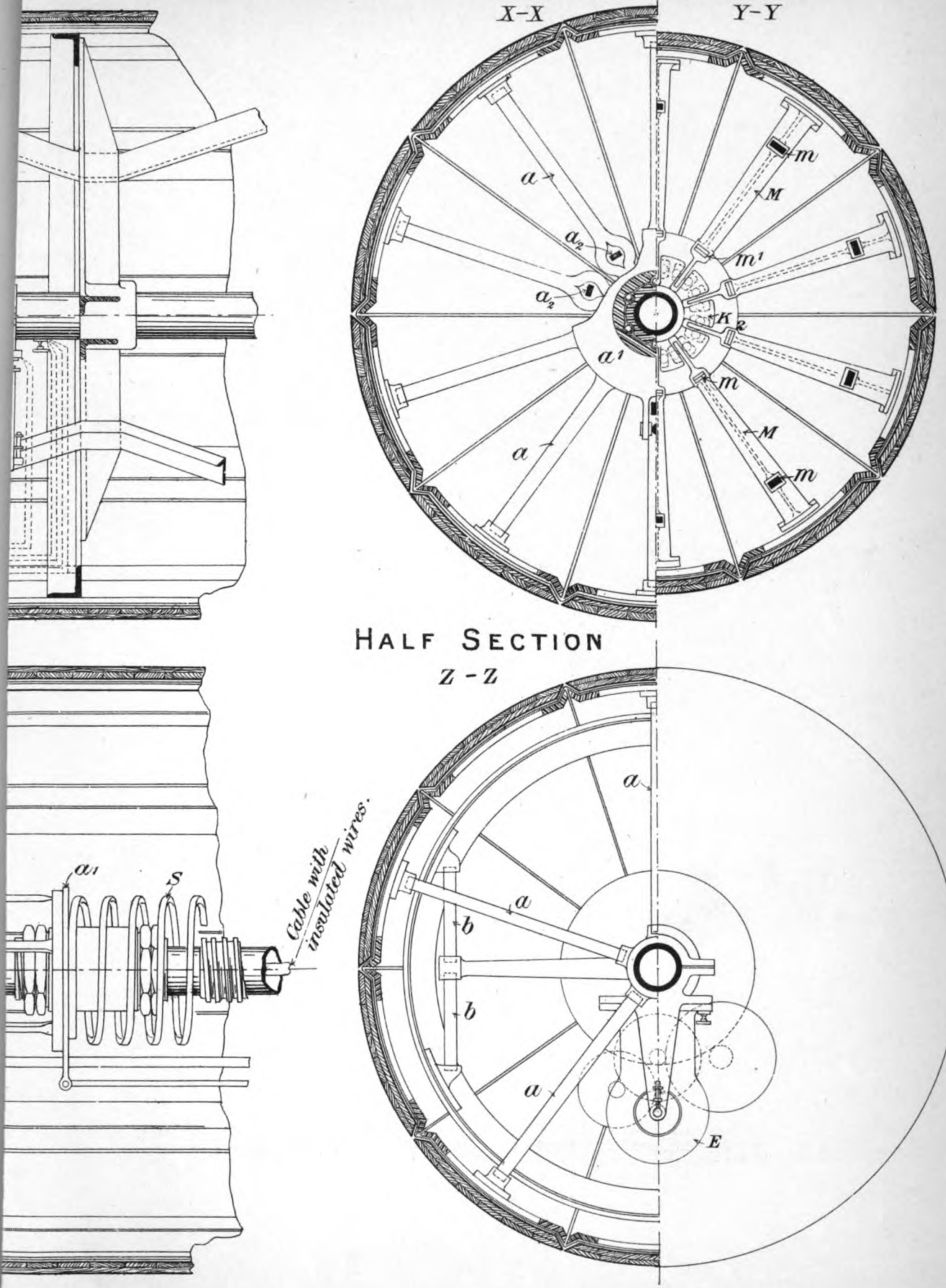

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To Illustrate Mr. A. F. Yarrow's Paper: Description of some Experiments with a Water Tube Boiler.

FIG. 1.

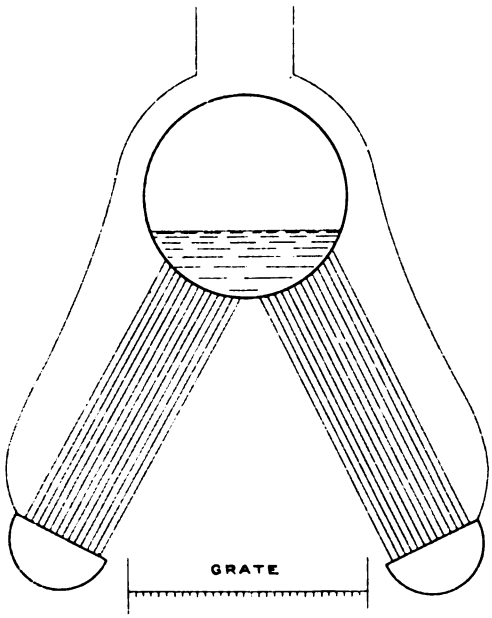


FIG. 3.

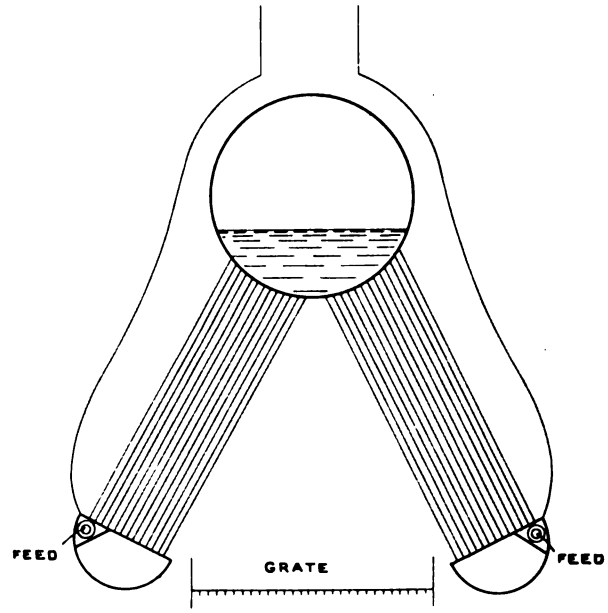
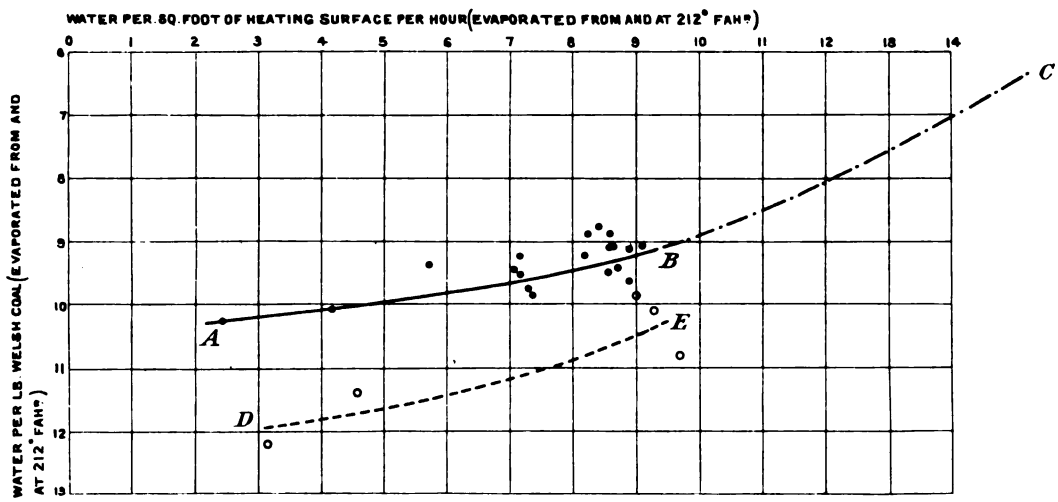


FIG. 2.

SHEWING RESULTS OF EVAPORATION TESTS OF "YARROW" BOILER


WATER PER SQ. FOOT OF HEATING SURFACE PER HOUR (EVAPORATED FROM AND AT 212° FAHR.)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
6 7 8 9 10 11 12 13
WATER PER LB. WELSH COAL (EVAPORATED FROM AND AT 212° FAHR.)
A
B
C
D
E

NOTE. The full line has reference to a "Yarrow" Boiler with all tubes embraced in general circulation. The dotted line has reference to same "Yarrow Boiler with 3 outer rows of tubes supplied direct from feed pump and consequently colder than under previous conditions.

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Tube Boiler.

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To Illustrate Mr. A. F. Yarrow's Paper: Description of some Experiments with a Water Tube Boiler.

FIG. 1.

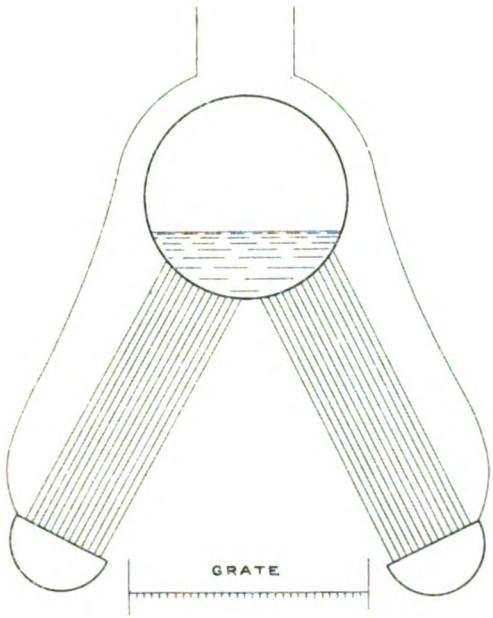
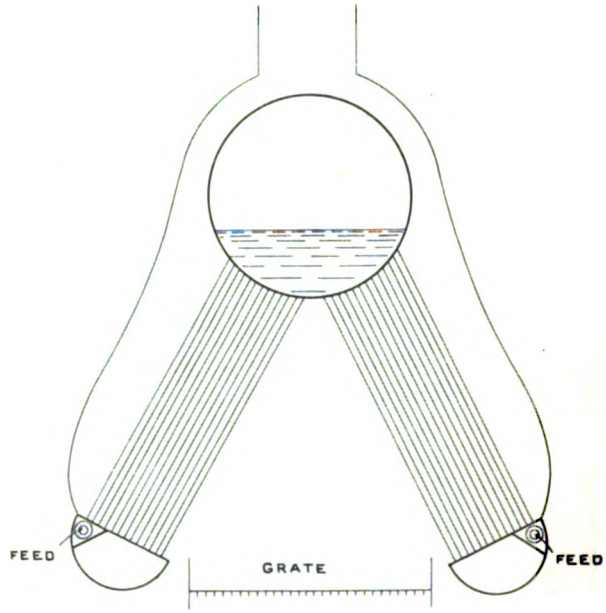


FIG. 3.



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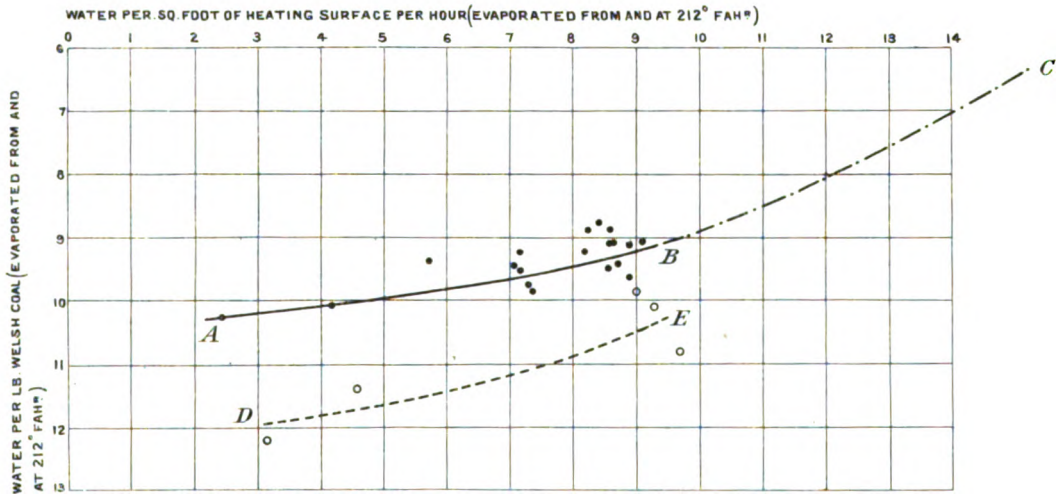

NOTE. *The full line has reference to a "Yarrow" Boiler with all tubes embraced in general circulation. The dotted line has reference to same "Yarrow" Boiler with 3 outer rows of tubes supplied direct from feed pump and consequently colder than under previous conditions.*

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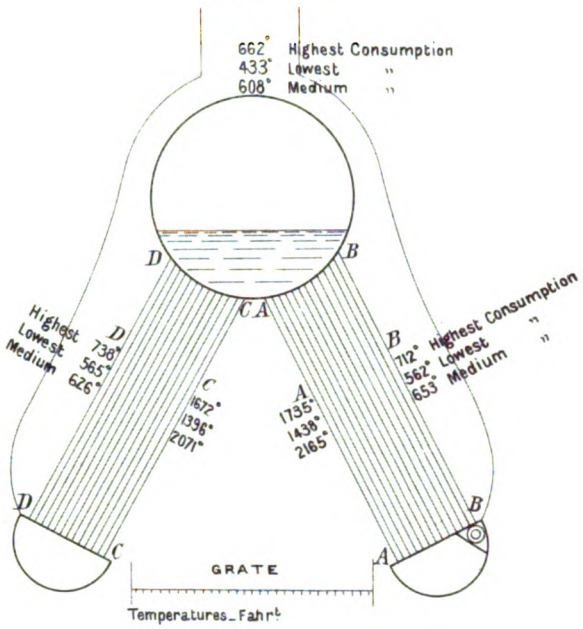
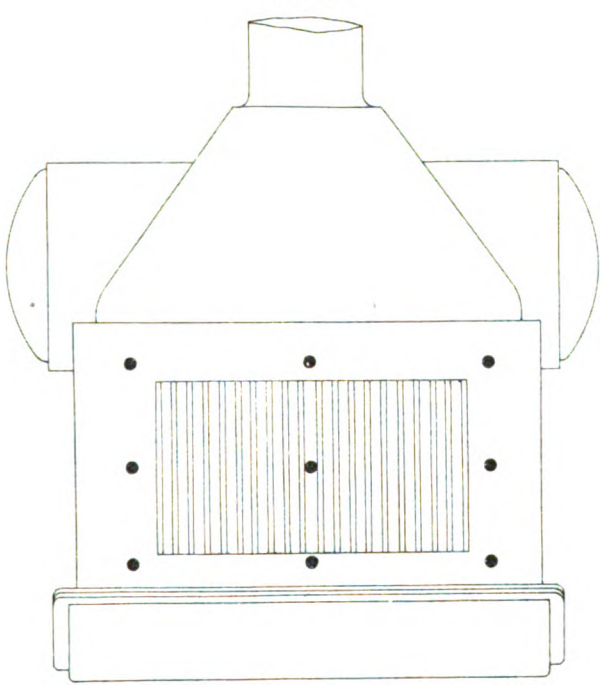
To Illustrate Mr. A. F. Yarrow's Paper: Description of some Experiments with a Water Tube Boiler.

FIG. 4



TRIAL Nº	PRESSURE IN LBS □"	CONSUMº PER SQ. FT OF GRATE	FEED SIDE FACE A	FEED SIDE FACE B	OTHER SIDE FACE C	OTHER SIDE FACE D	EXCESS DIFF IN FAVOUR OF FEED SIDE (FAHRº)	FUNNEL TEMP. (FAHRº)
			FAHRº					
I	180	52 LBS	1735°	712°	1672°	738°	89°	662°
			DIFF = 1023°		DIFF = 934°			
II	180	19 LBS	1438°	562°	1396°	565°	45°	433°
			DIFF = 876°		DIFF = 831°			
III	180	31·4 LBS.	2165°	653°	2071°	626°	67°	608°
			DIFF = 1512°		DIFF = 1445°			

FIG. 5.



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THE "GARRYOWEN" AT LIMERICK.

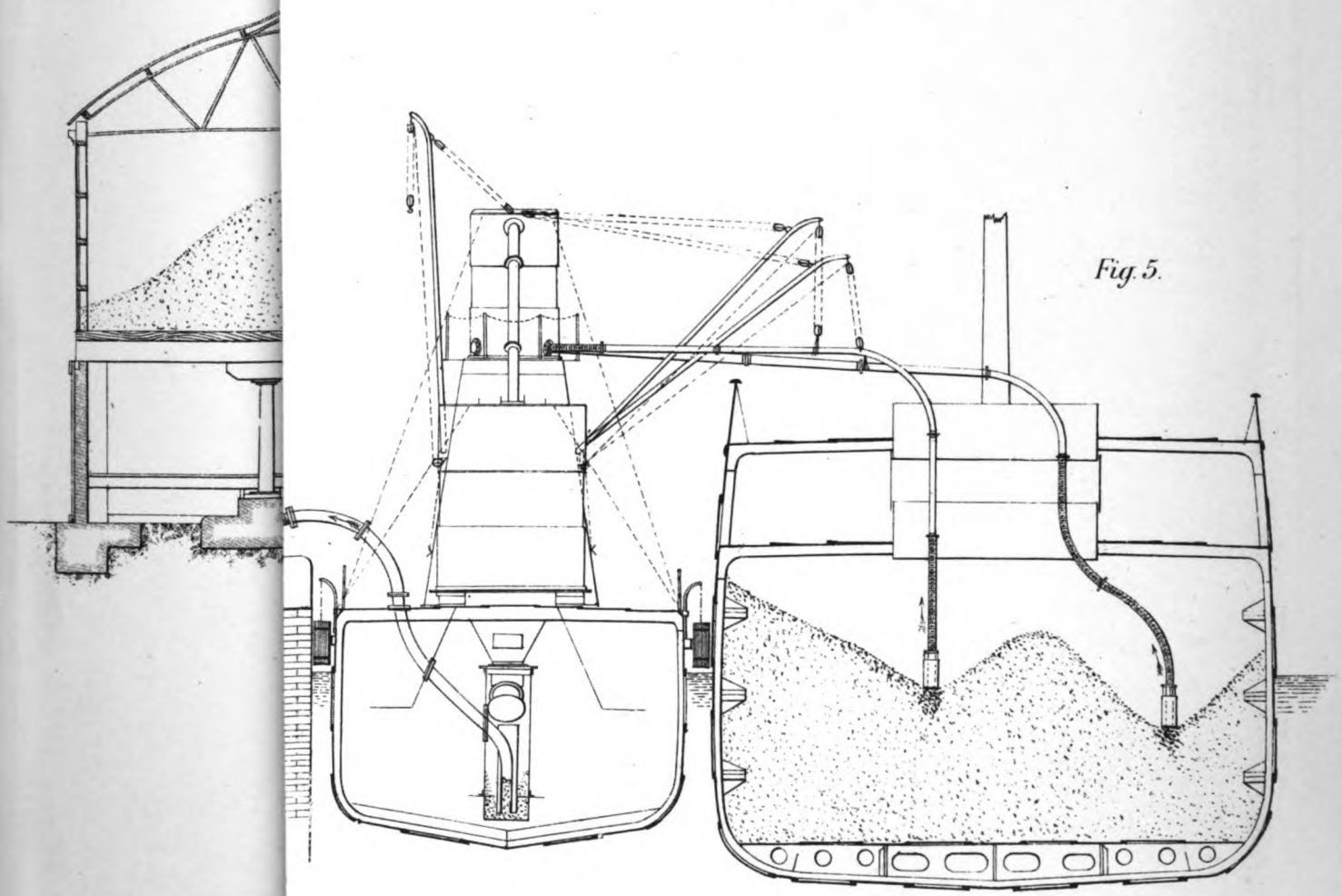

Fig. 5.

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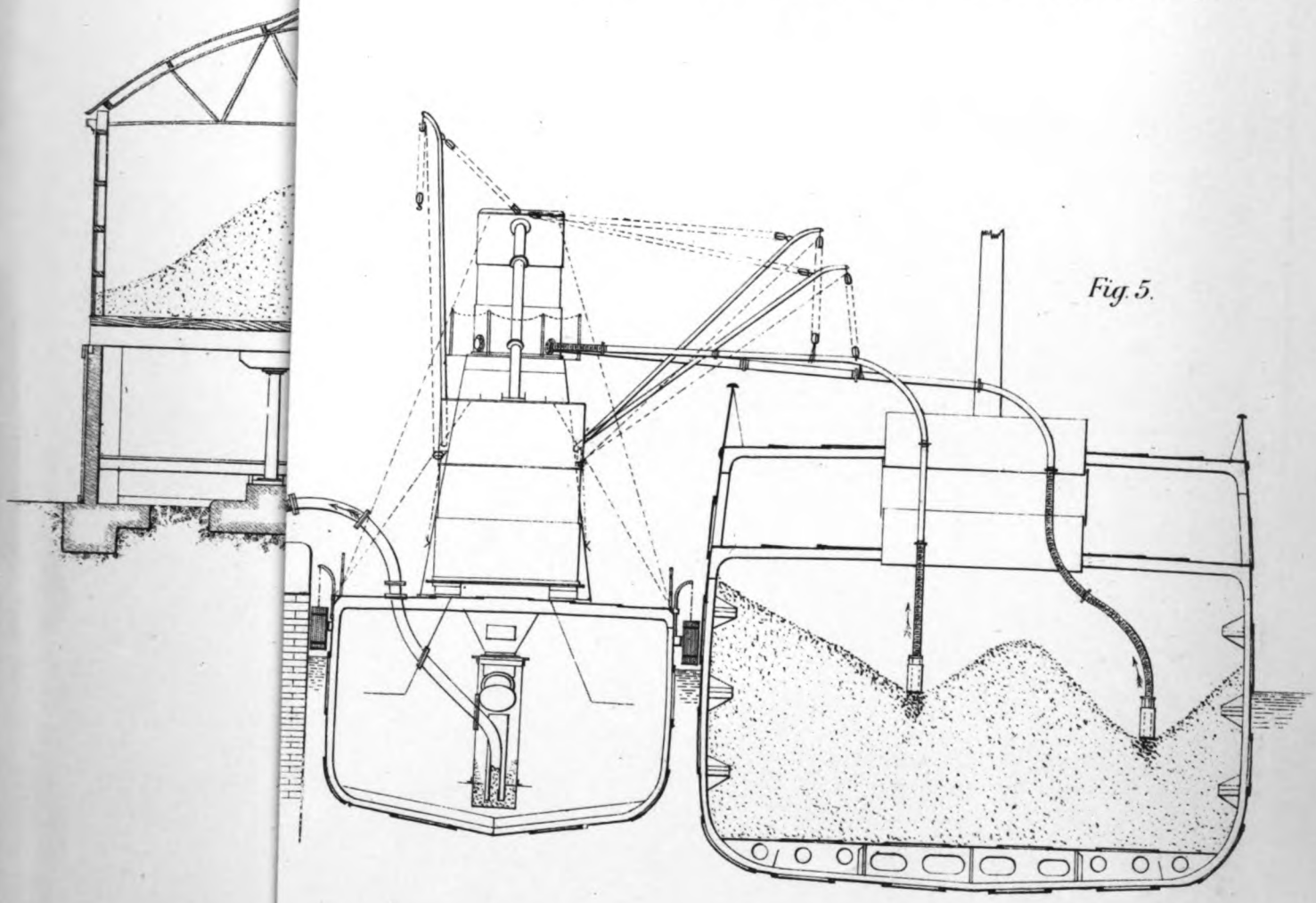

Fig. 5.

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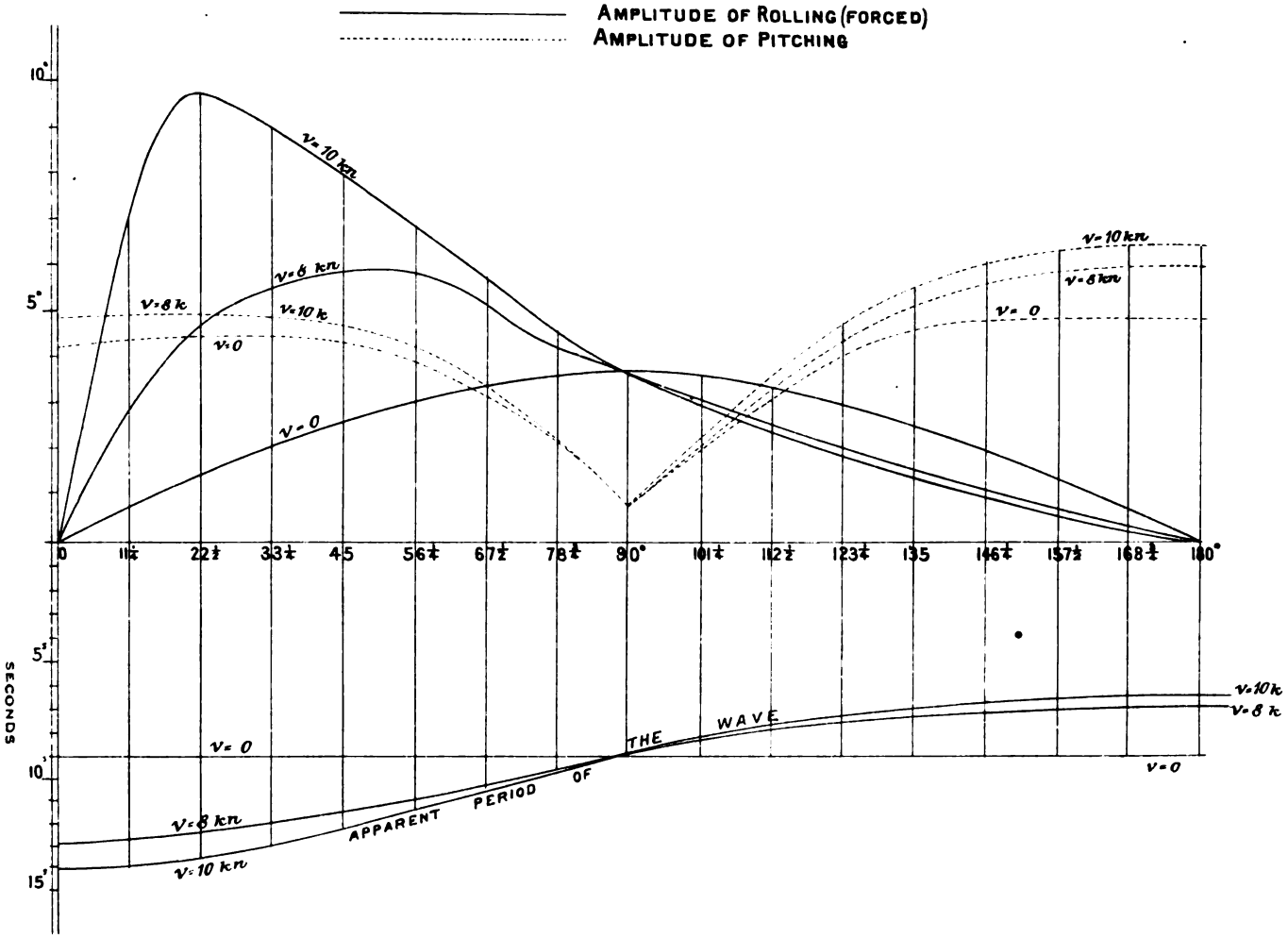
To Illustrate Captain A. Kriloff's Paper: A general Theory of the Oscillations of a Ship on Waves.

DIAGRAM, SHOWING THE VARIATION OF THE AMPLITUDES OF PITCHING AND ROLLING WITH THE COURSE HEAD AND SPEED OF THE SHIP



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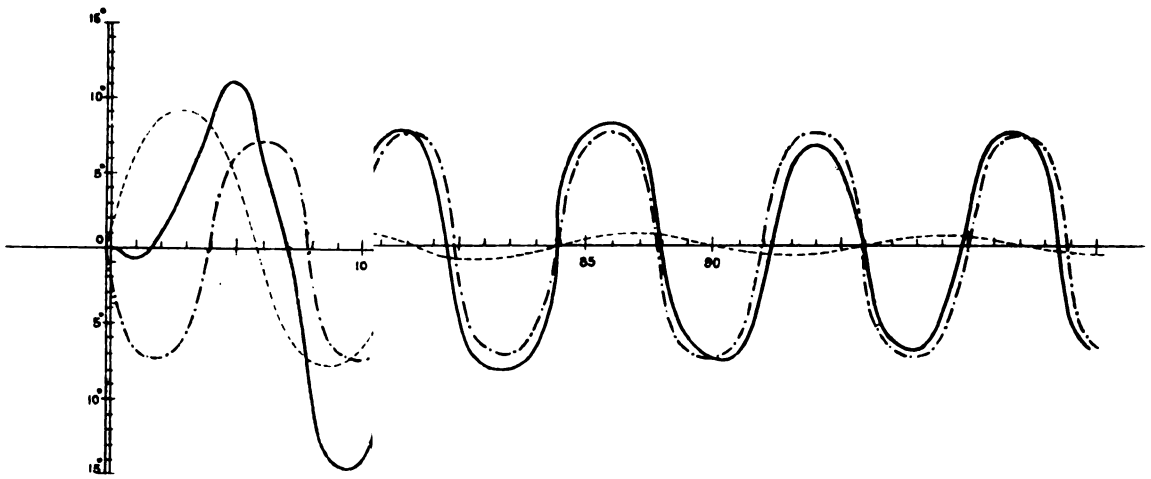

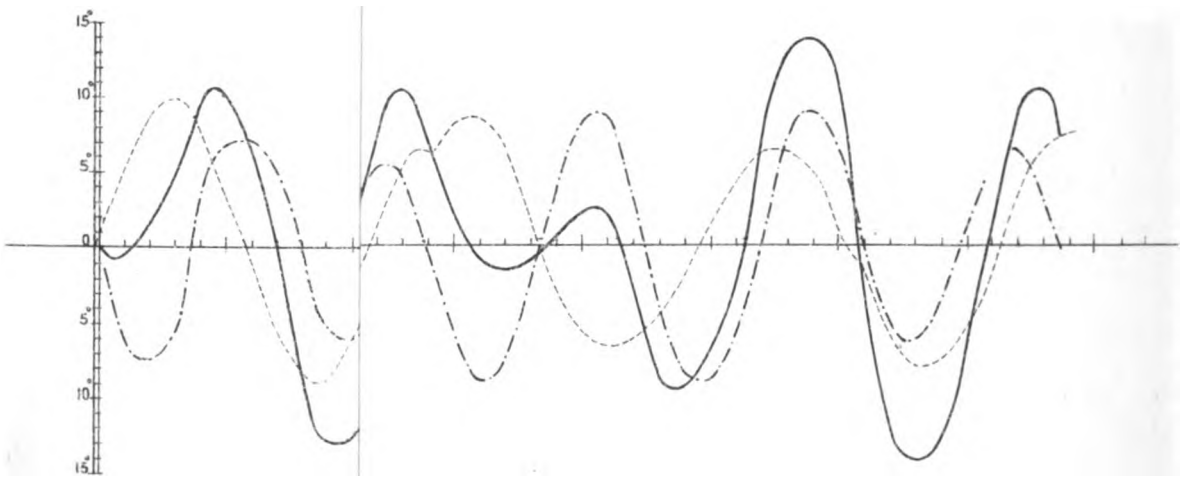

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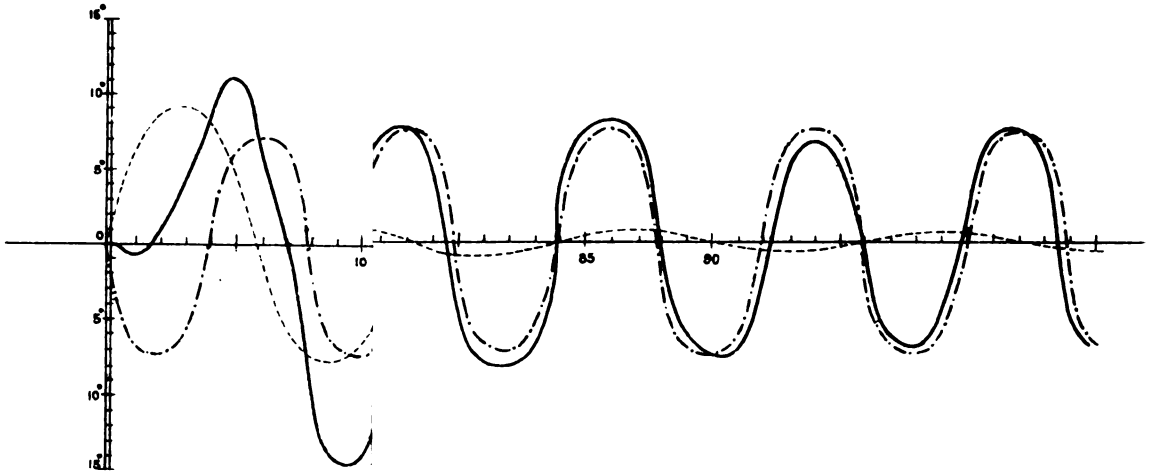

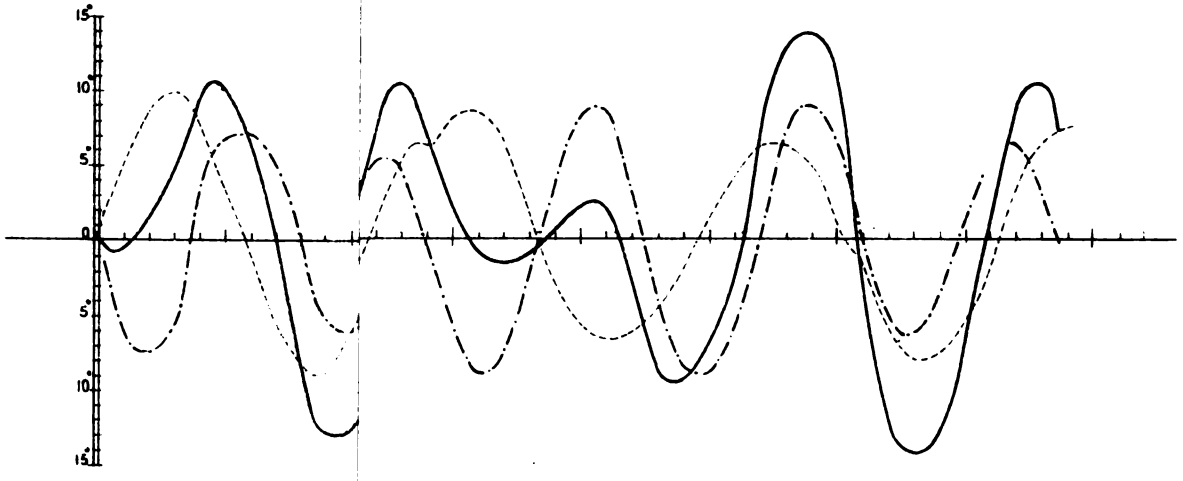

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FIG. 1.

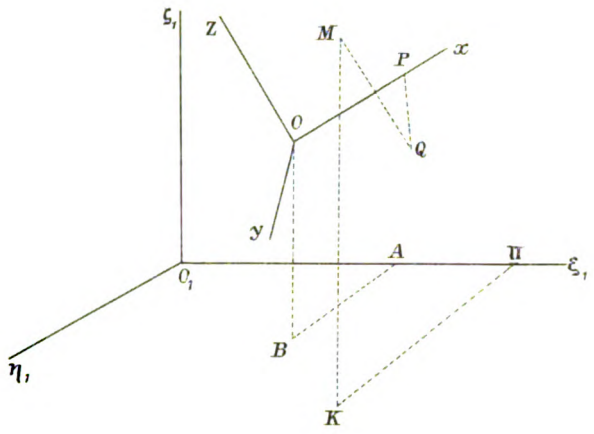


FIG. 2.

EULERIAN ANGLES ψ φ θ AS USUALLY DEFINED

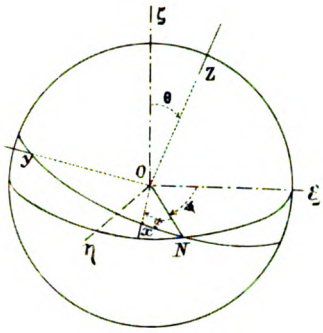
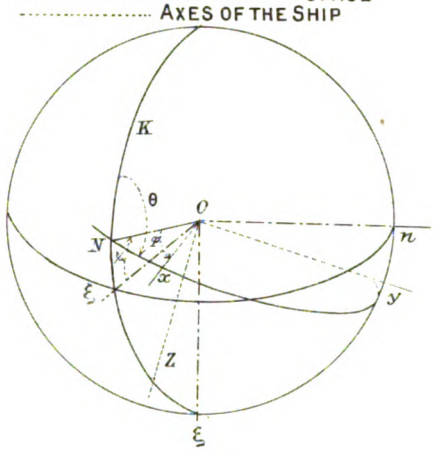


FIG. 3.

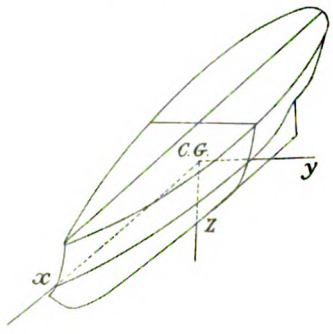
EULERIAN ANGLES ψ φ θ SPECIALLY ADAPTED TO SHIPS ASCILLATIONS

AXES FIXED IN SPACE

AXES OF THE SHIP



DISPOSITION OF SHIPS AXES



PROFILE

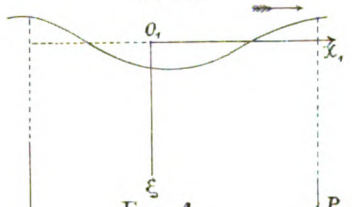


FIG. 4

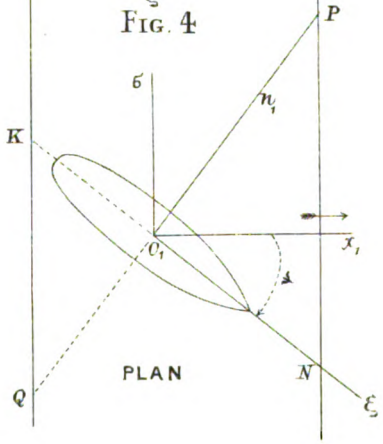
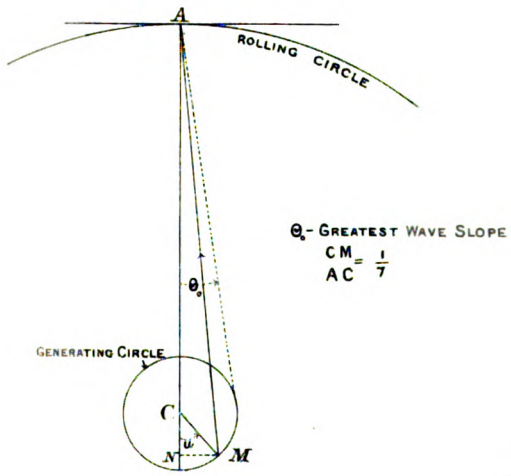


FIG. 5.



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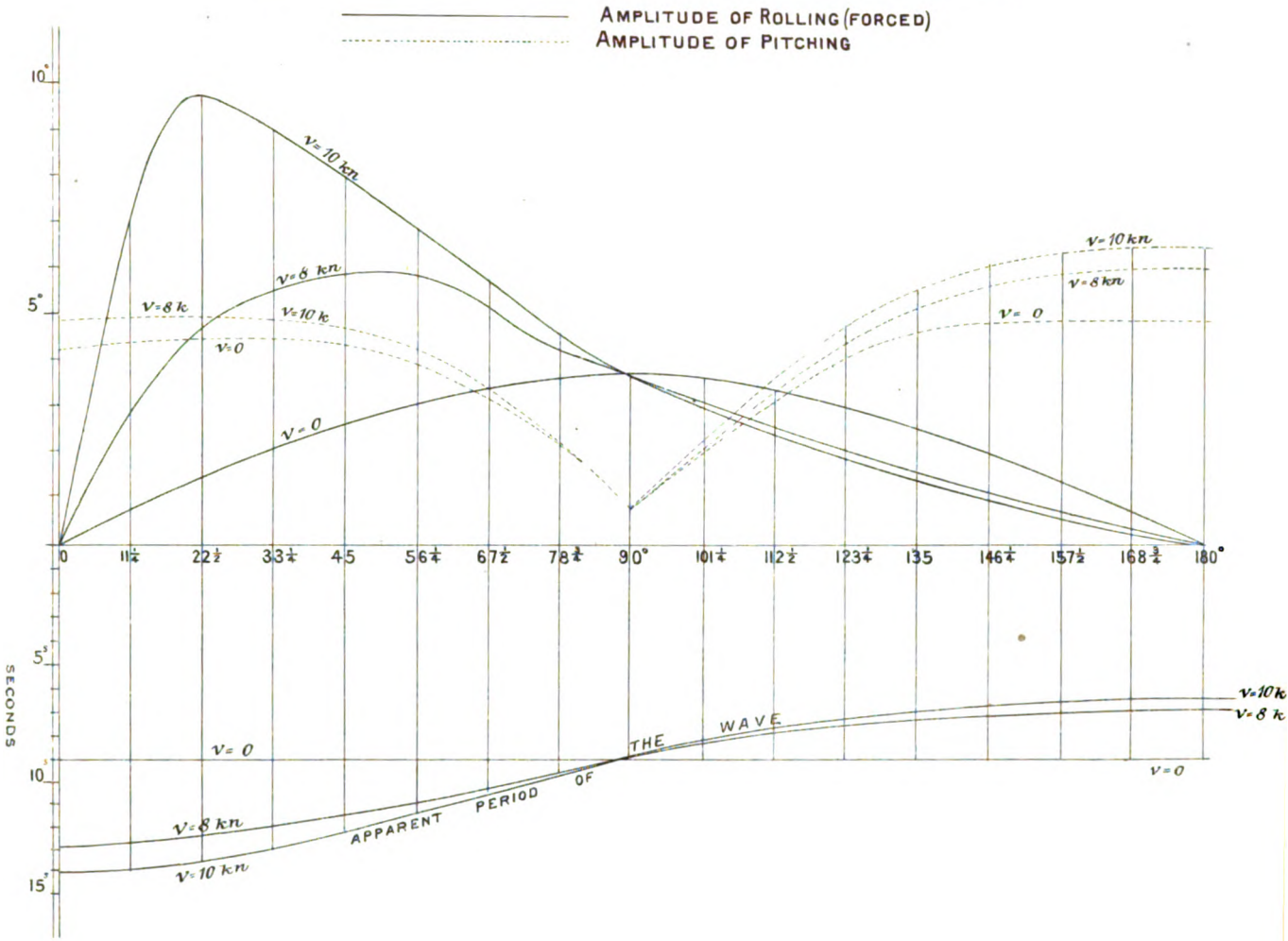
To Illustrate Captain A. Kriloff's Paper: A general Theory of the Oscillations of a Ship on Waves.

DIAGRAM, SHOWING THE VARIATION OF THE AMPLITUDES OF PITCHING AND ROLLING WITH THE COURSE HEAD AND SPEED OF THE SHIP



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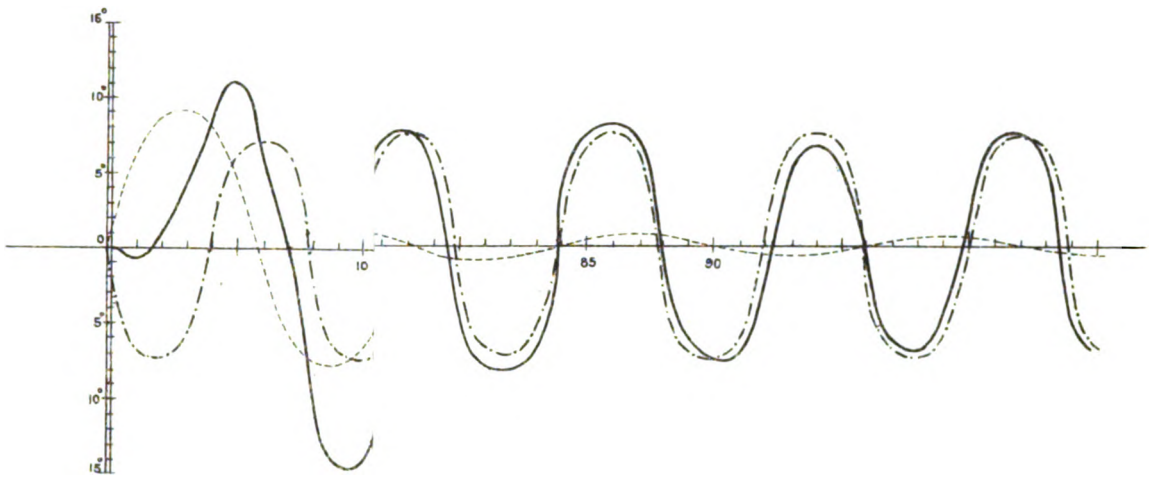

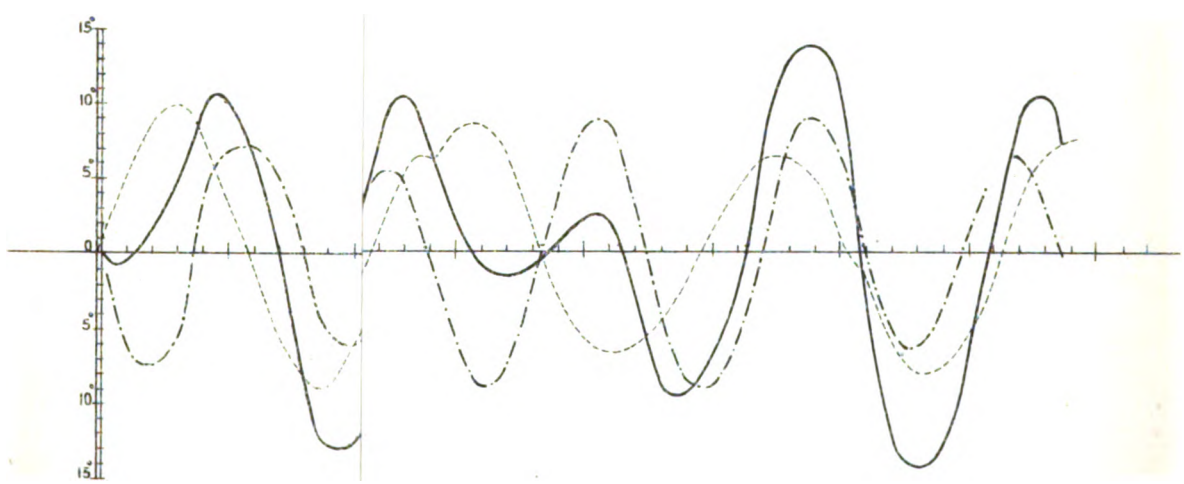

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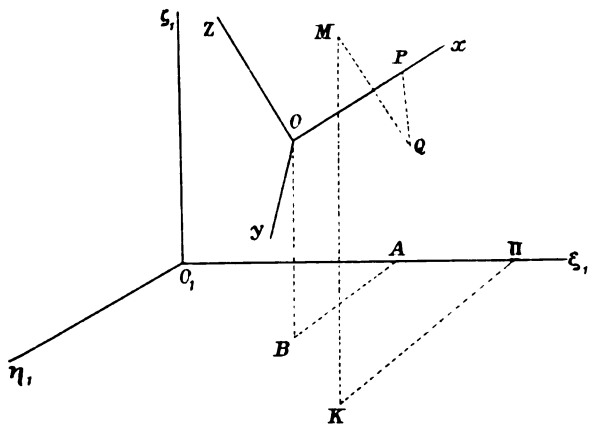
FIG. 1.



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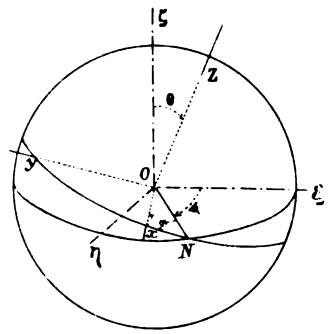

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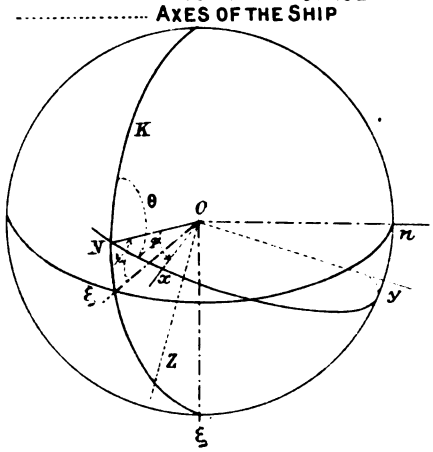
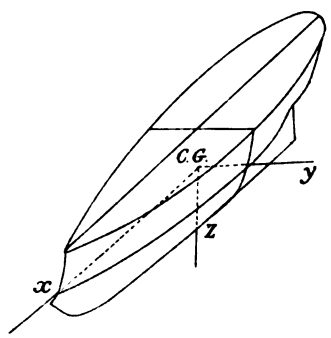
AXES FIXED IN SPACE

AXES OF THE SHIP



DISPOSITION OF SHIPS AXES



PROFILE

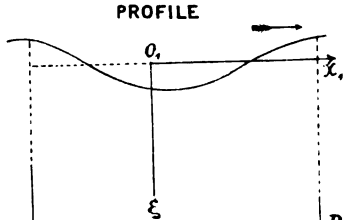
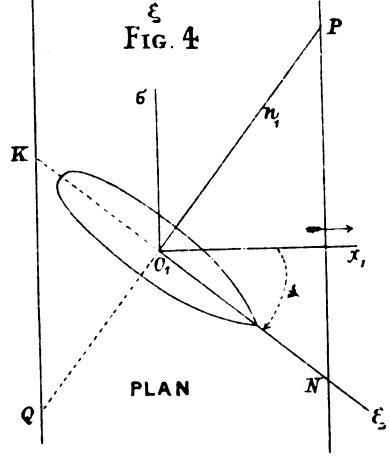
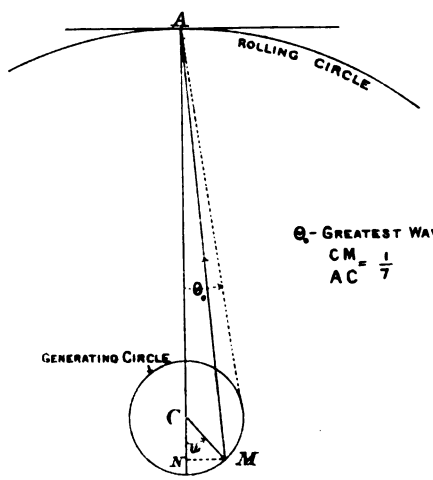


FIG. 4



PLAN

FIG. 5.



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To Illustrate Captain A. Kriloff's Paper: A general Theory of the Oscillations of a Ship on Wave.

DIAGRAMS OF THE EQUILIBRIUM POSITIONS OF A SHIP ON WAVES

FIG. 1.

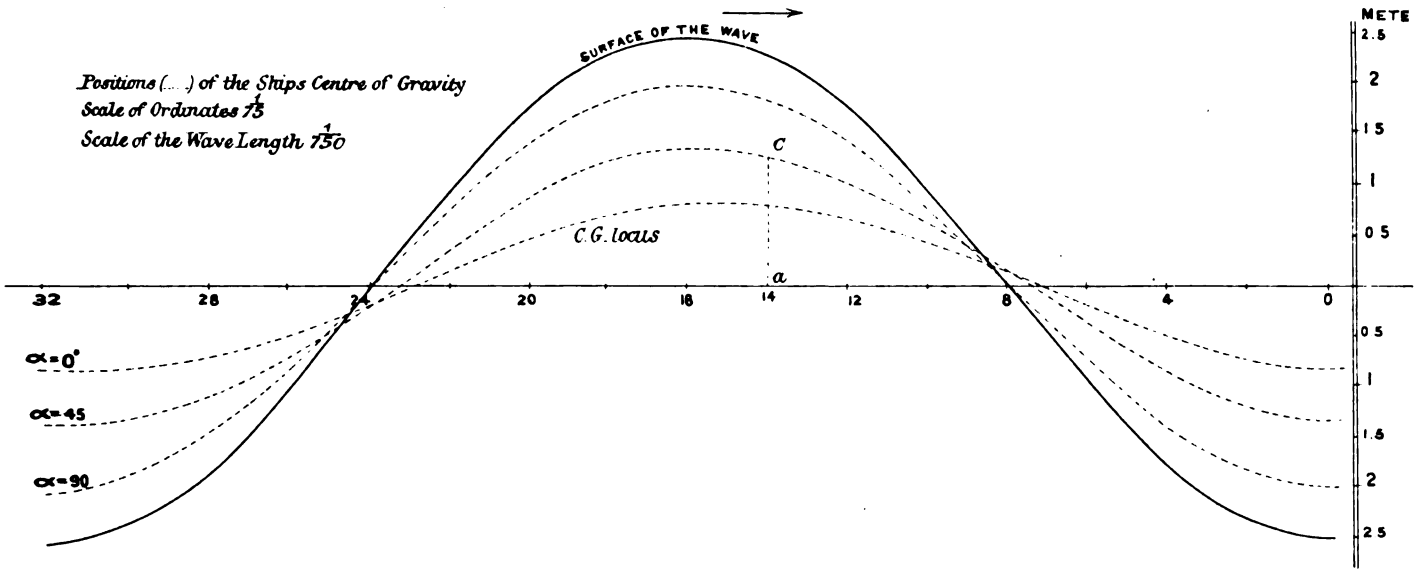
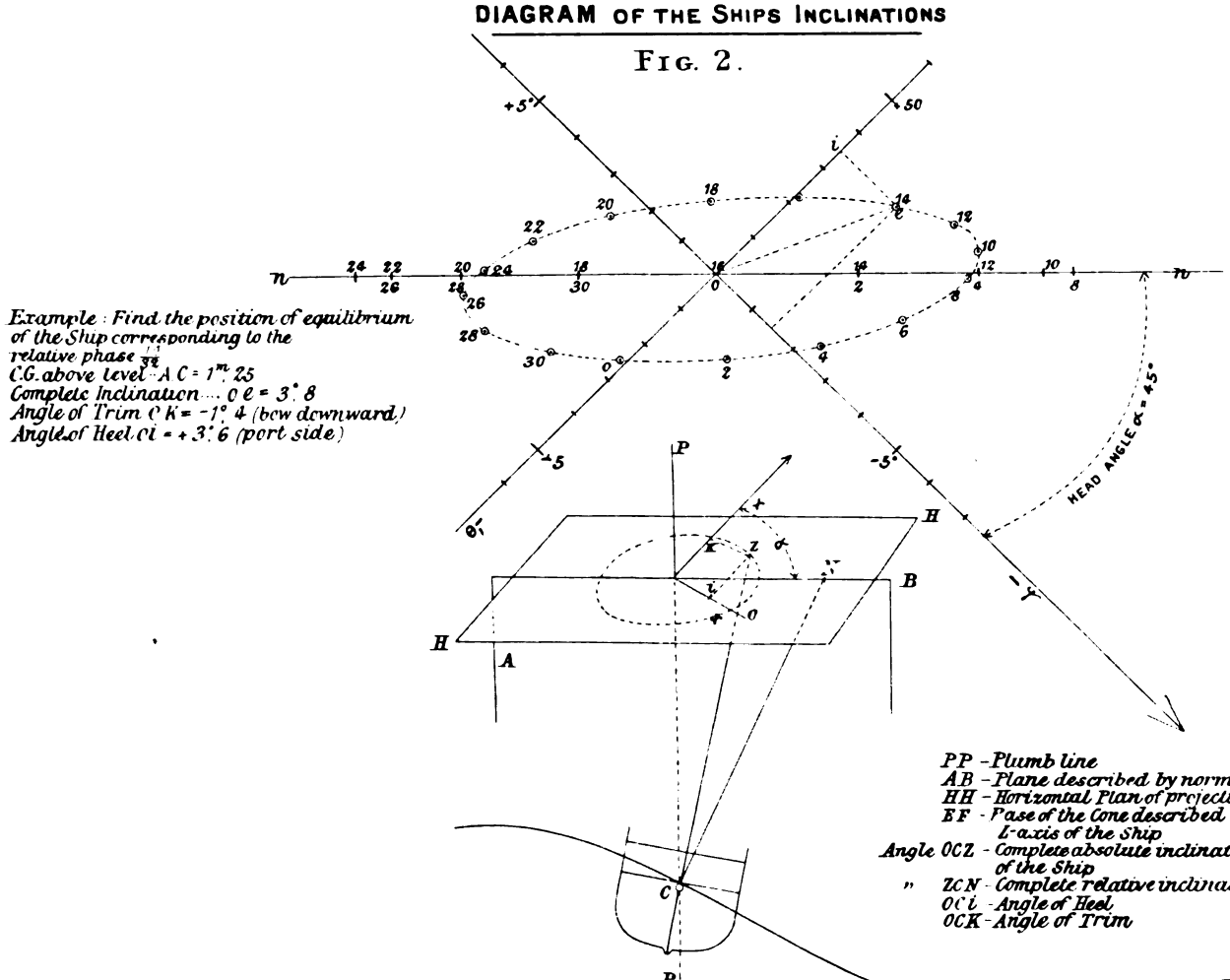


DIAGRAM OF THE SHIPS INCLINATIONS

FIG. 2.


Example: Find the position of equilibrium of the Ship corresponding to the relative phase 11/12
C.G. above level A C = 1m. 25
Complete Inclination ..... O E = 3°. 8
Angle of Trim C K = -1°. 4 (bow downward.)
Angle of Heel C i = +3°. 6 (port side.)
+5°
-5°
50
HEAD ANGLE α = 45°
P
H
B
A
C
P
PP - Plumb line
AB - Plane described by normal to the W
HH - Horizontal Plan of projection
EF - Base of the Cone described by the Z-axis of the Ship
Angle OCZ - Complete absolute inclination of the Ship
" ZCN - Complete relative inclination
OCi - Angle of Heel
OCK - Angle of Trim

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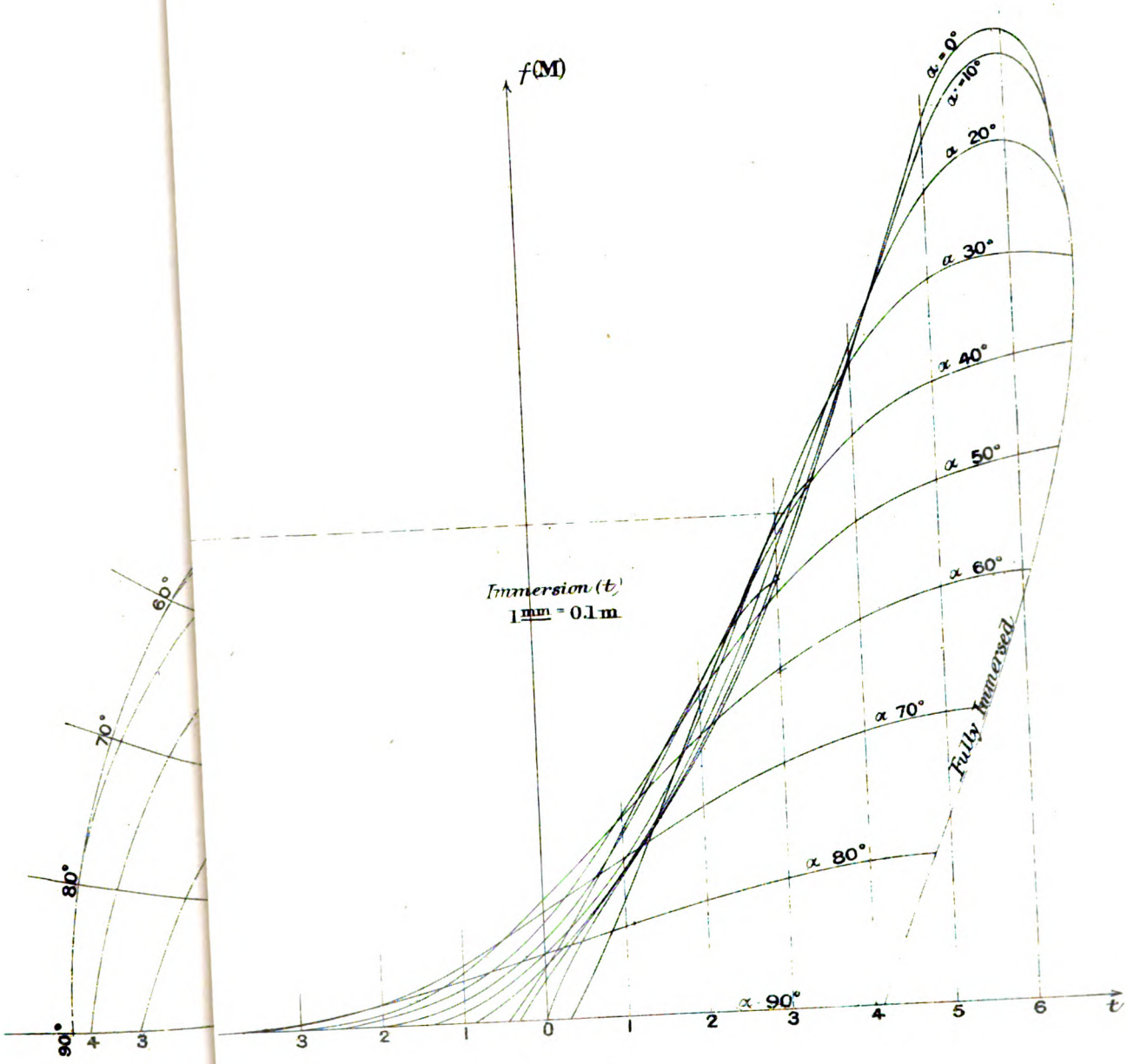

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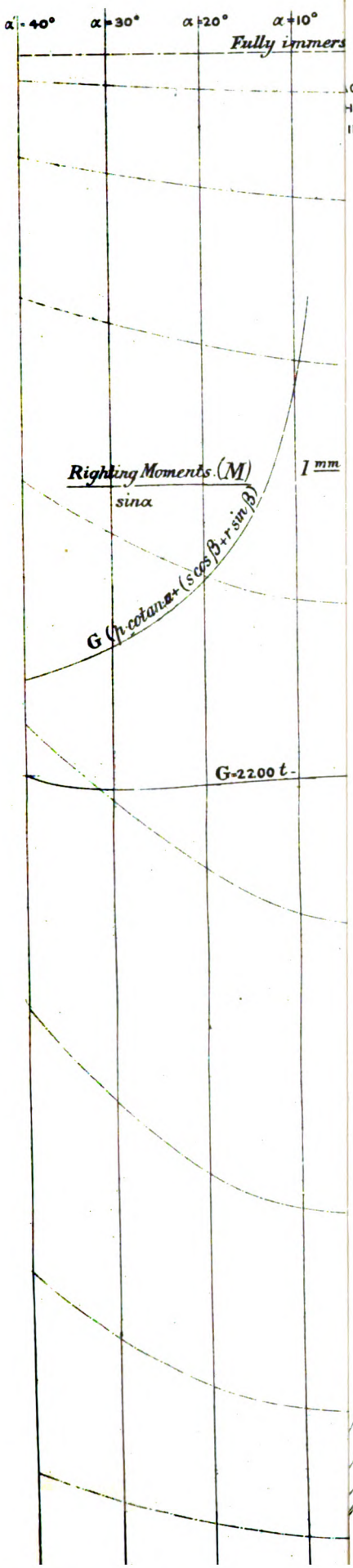
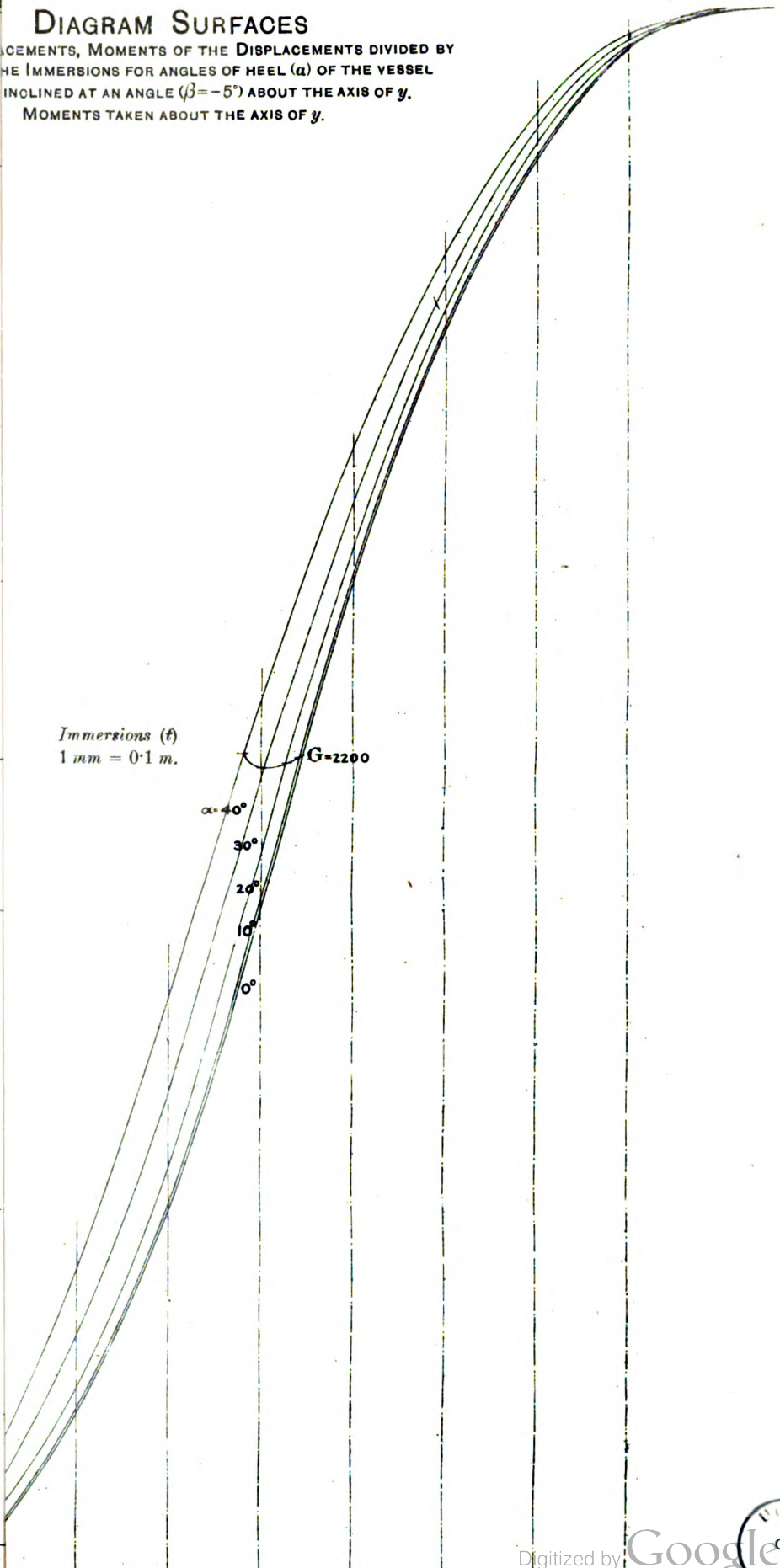
DIAGRAM SURFACES

...CEMENTS, MOMENTS OF THE DISPLACEMENTS DIVIDED BY
...HE IMMERSIONS FOR ANGLES OF HEEL (α) OF THE VESSEL
INCLINED AT AN ANGLE ($\beta = -5°$) ABOUT THE AXIS OF y.
MOMENTS TAKEN ABOUT THE AXIS OF y.





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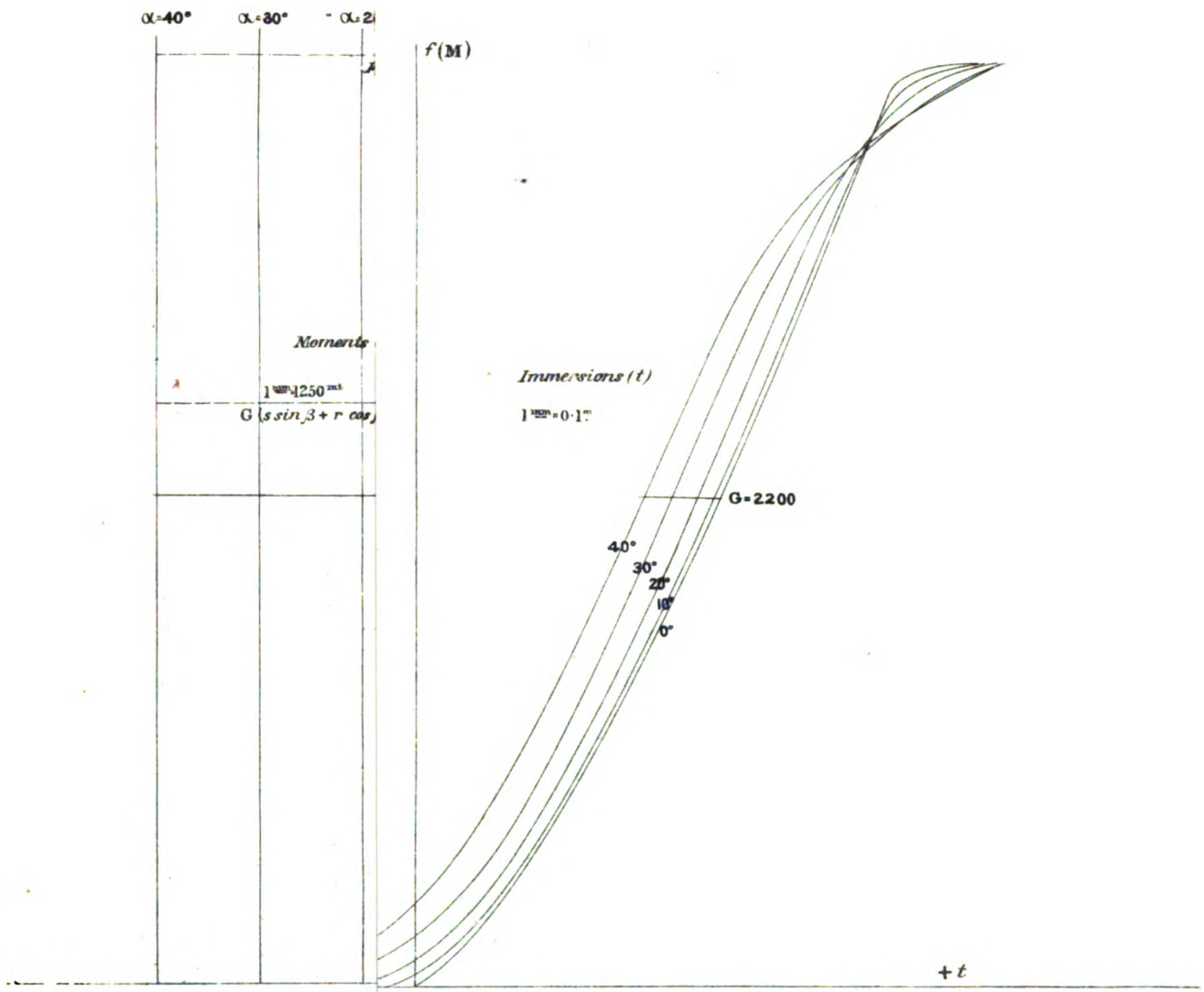

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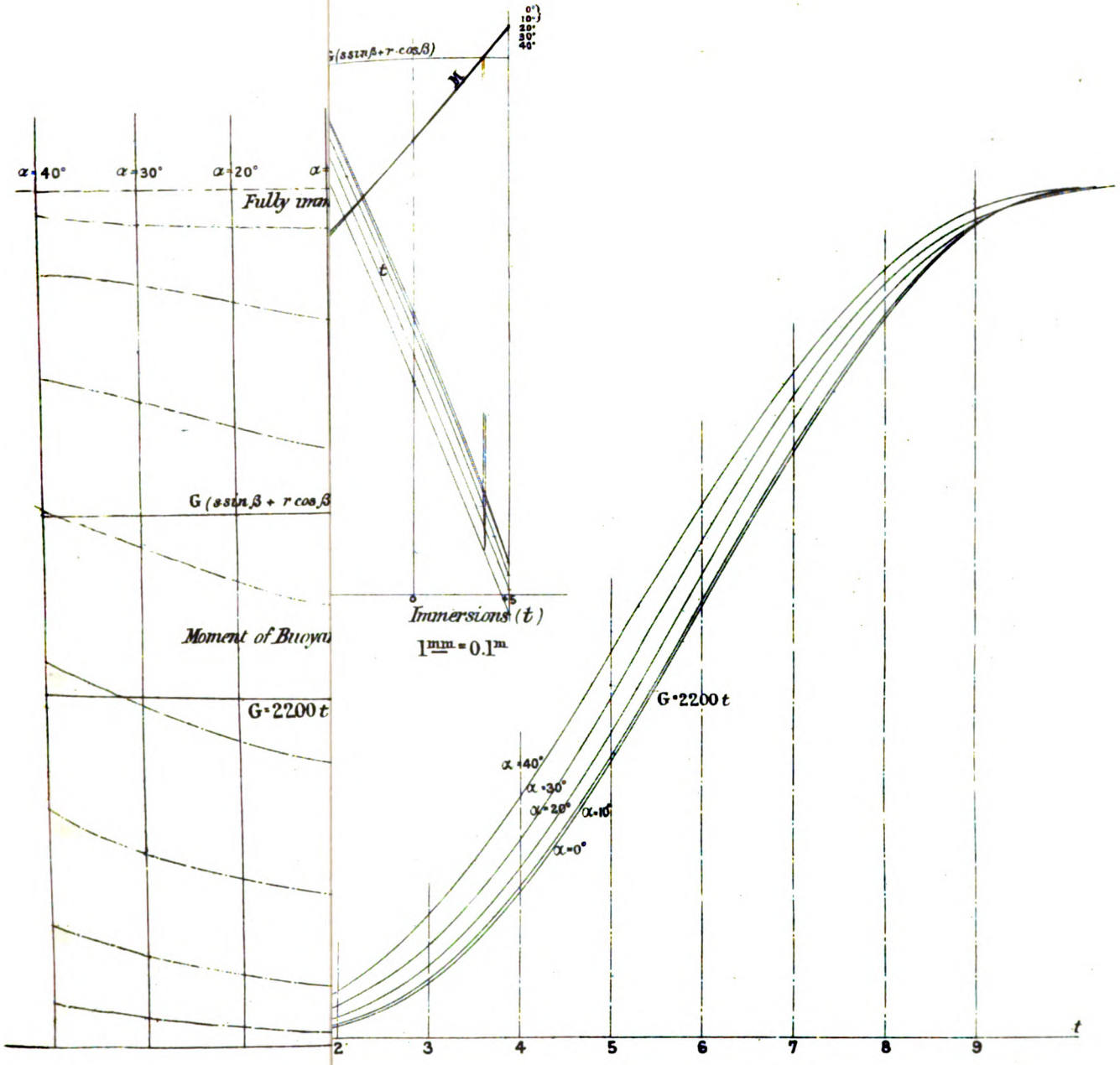

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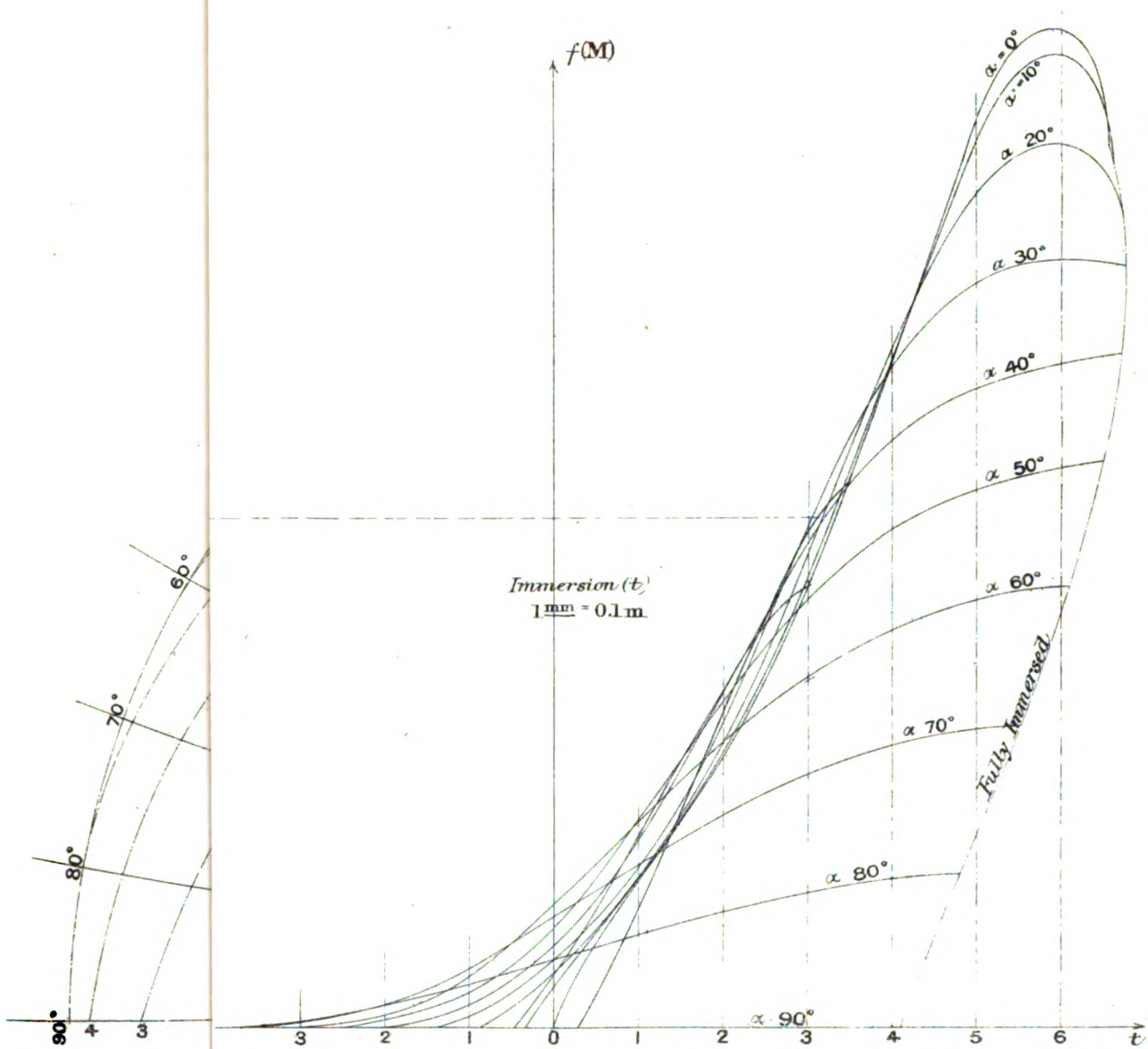

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Plate XLIX.

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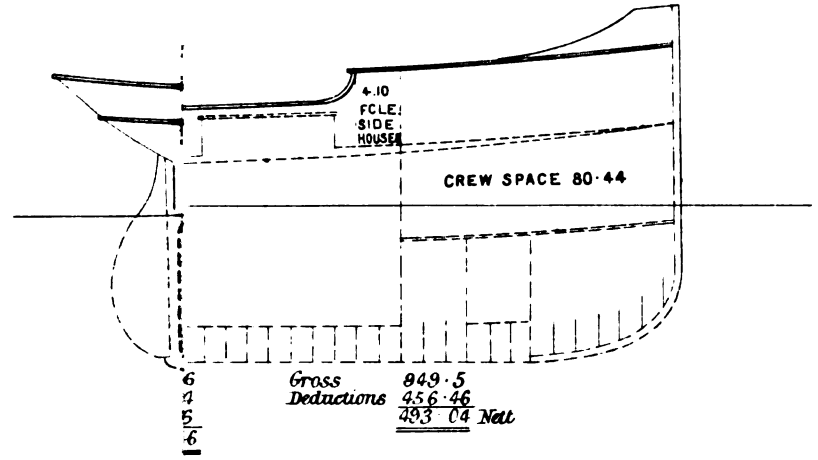

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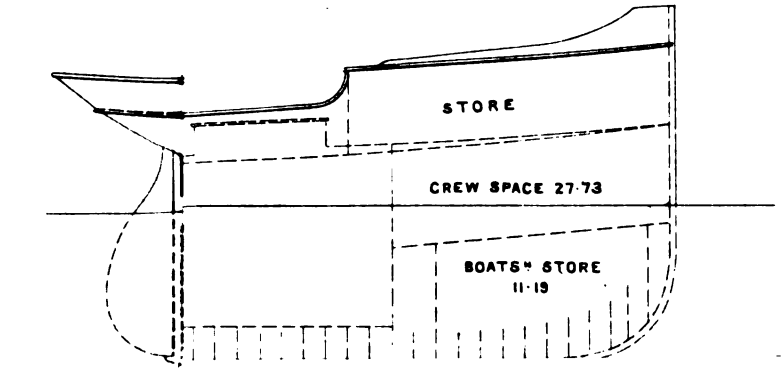

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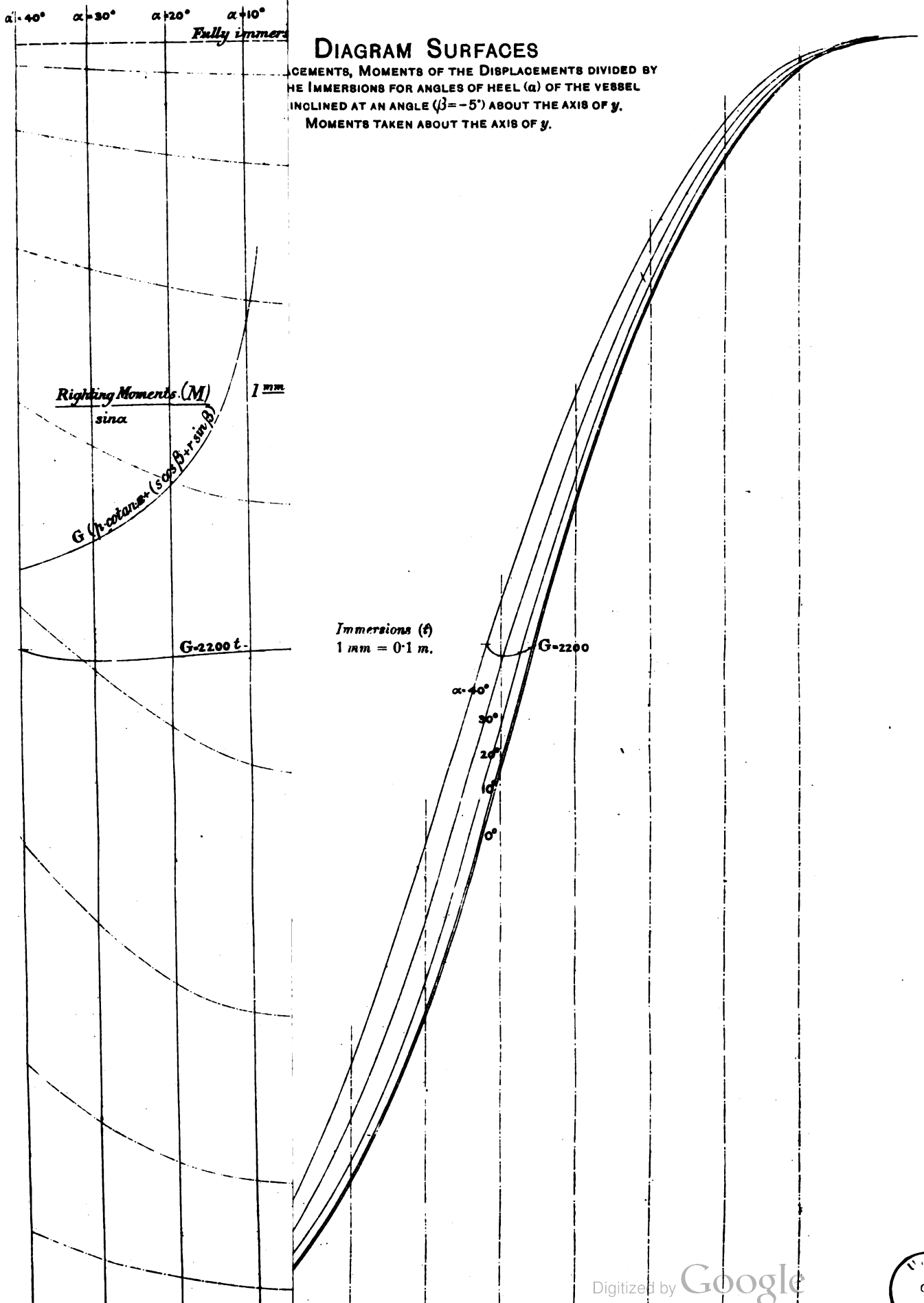

DIAGRAM SURFACES

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MOMENTS TAKEN ABOUT THE AXIS OF y.

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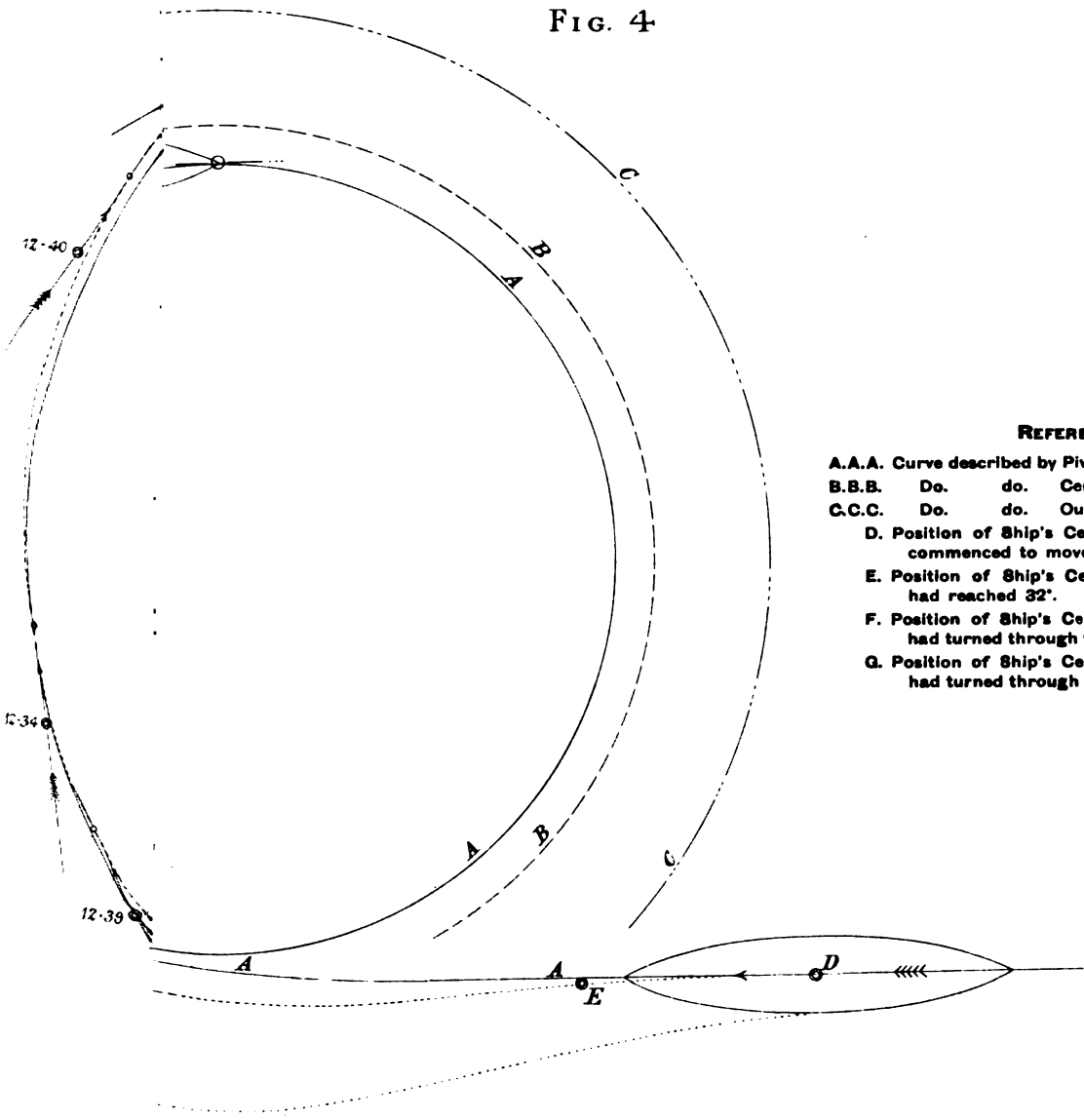
VERSED BY SHIP UNDER THE ACTION OF 32° OF HELM,
THE INITIAL SPEED OF 17·5 KNOTS.

FIG. 4



REFERENCES.

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F. Position of Ship's Centre of Gravity when vessel had turned through 90°. Time from D, 49½ s.
G. Position of Ship's Centre of Gravity when vessel had turned through 180°. Time from D, 1 m. 20 s

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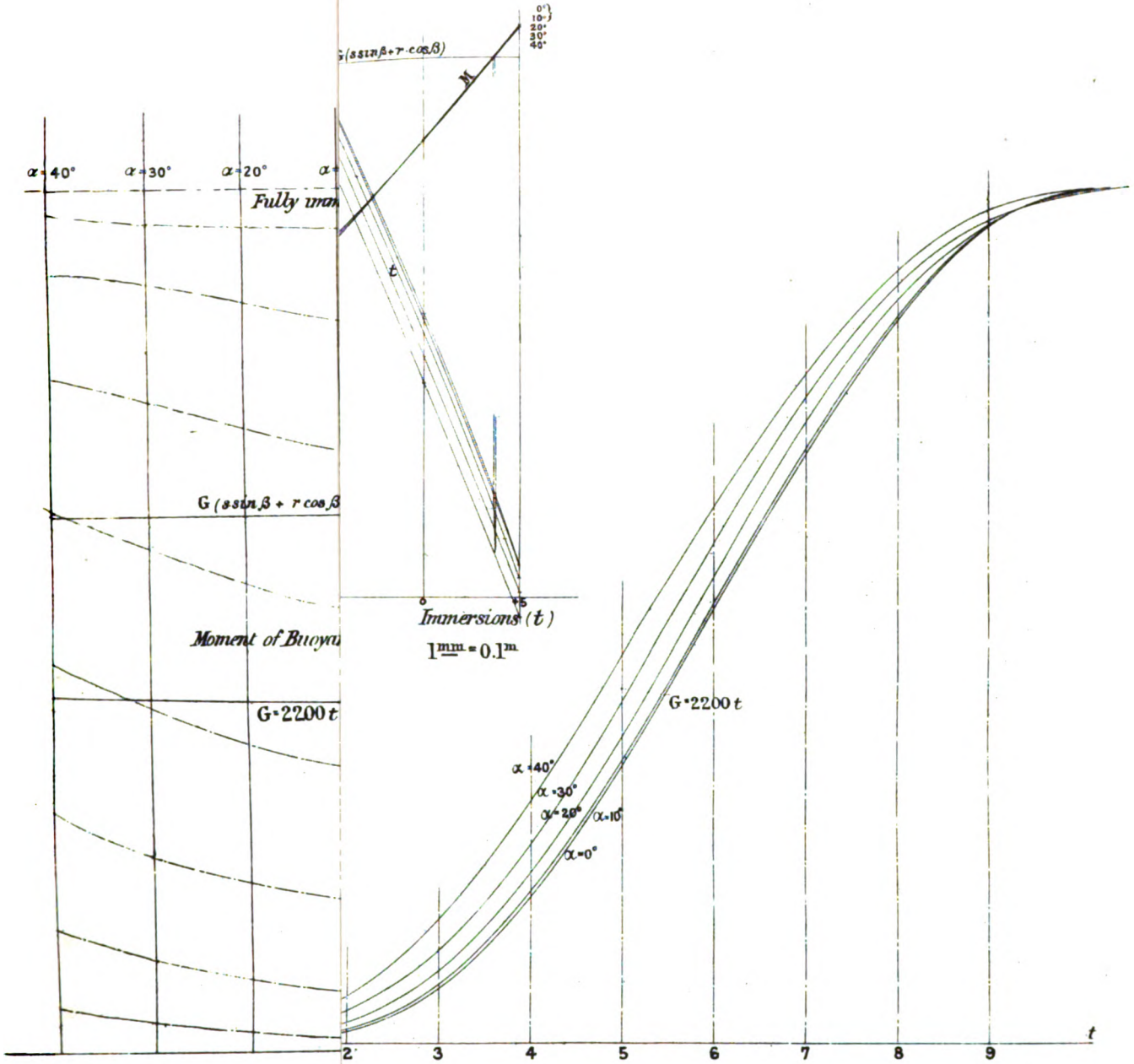

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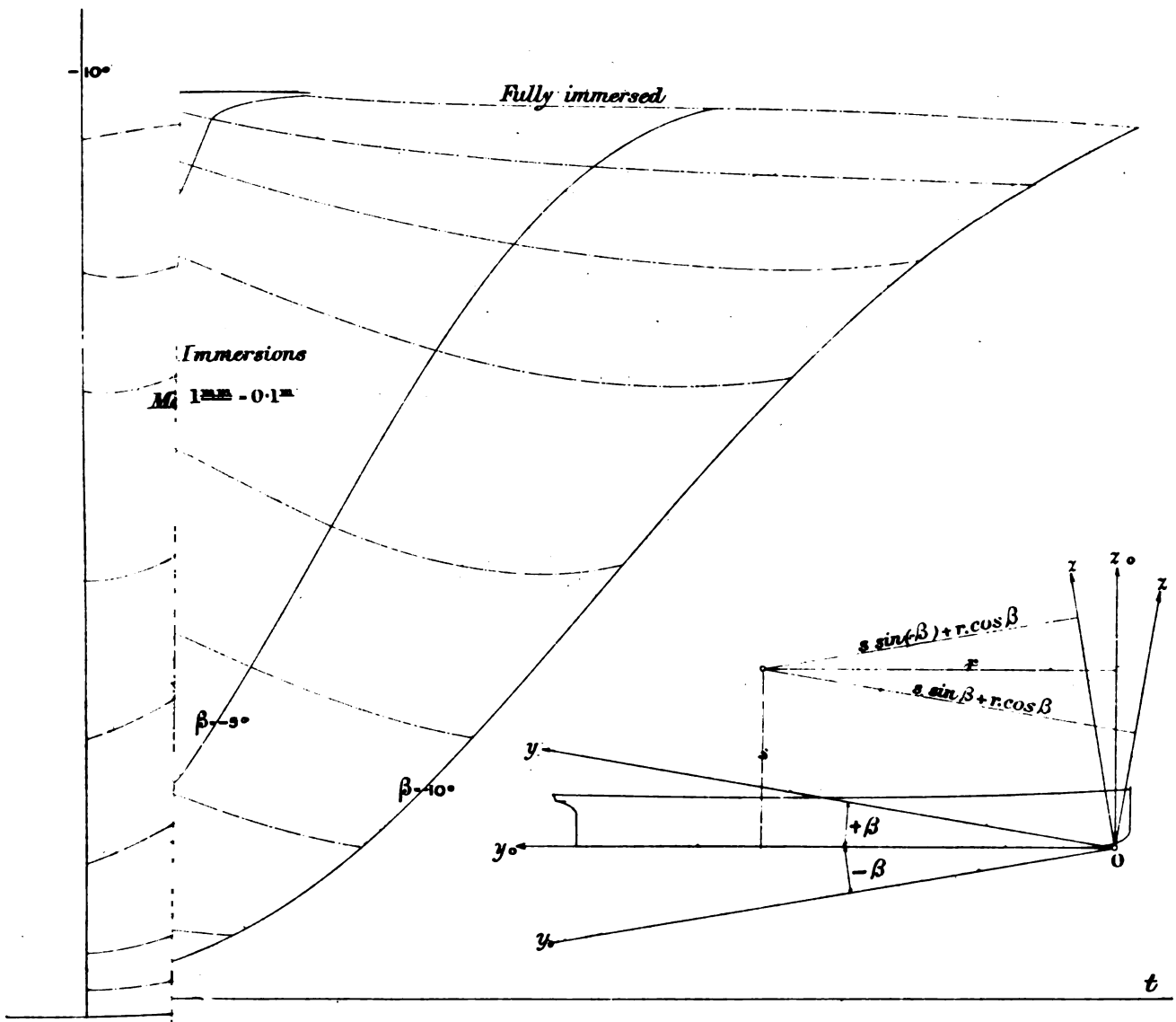

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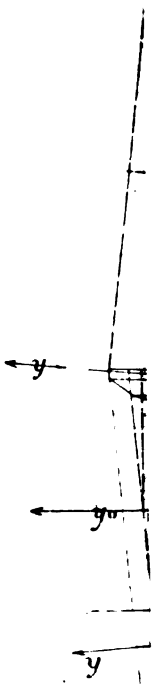

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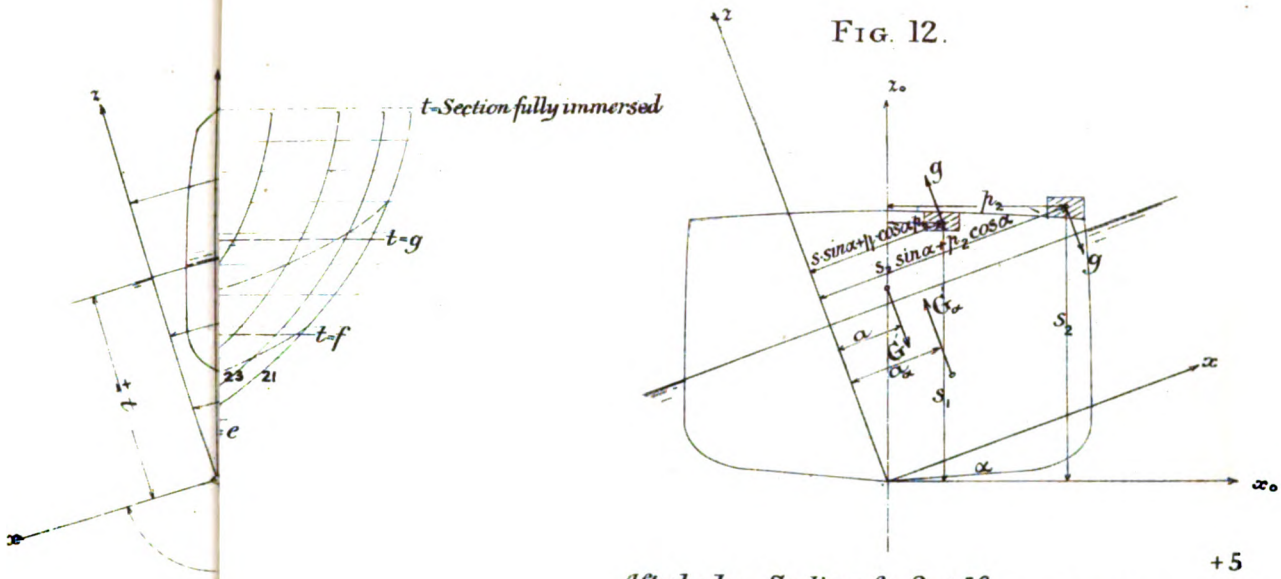
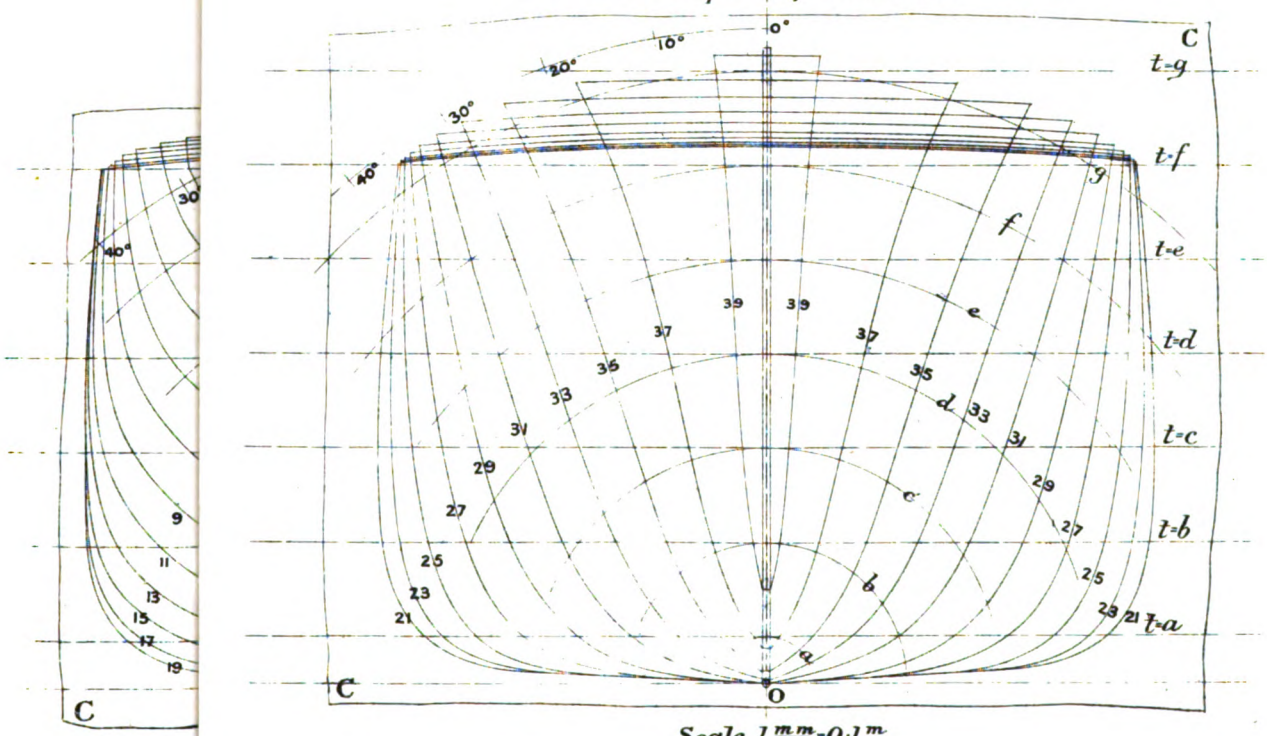
FIG. 12.



+5

Afterbody Sections for β=+5°
O in the plane of Sections 39

FIG. 9.



Scale 1 m.m.=0·1 m.

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To Illustrate Herr L. Gümbel's reply to the discussion on his Paper: The Problem of Stability in Naval Architecture.

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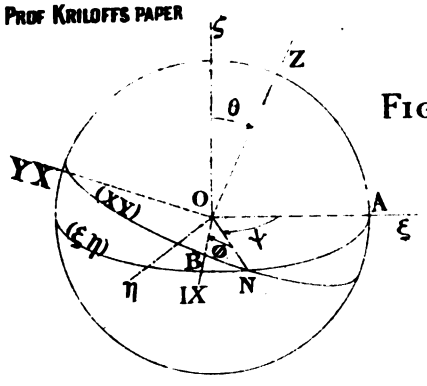

FIG. 1.

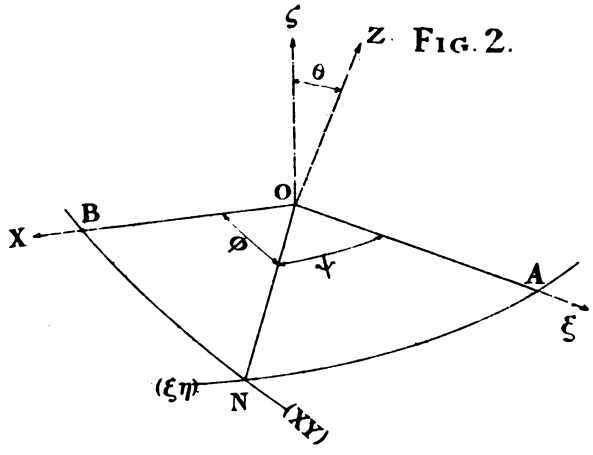

FIG. 2.

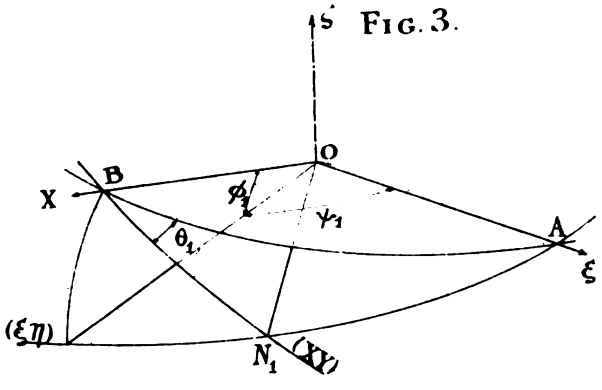

FIG. 3.

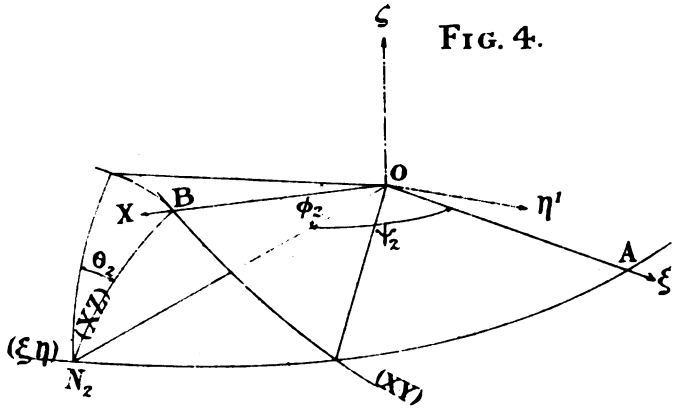

FIG. 4.

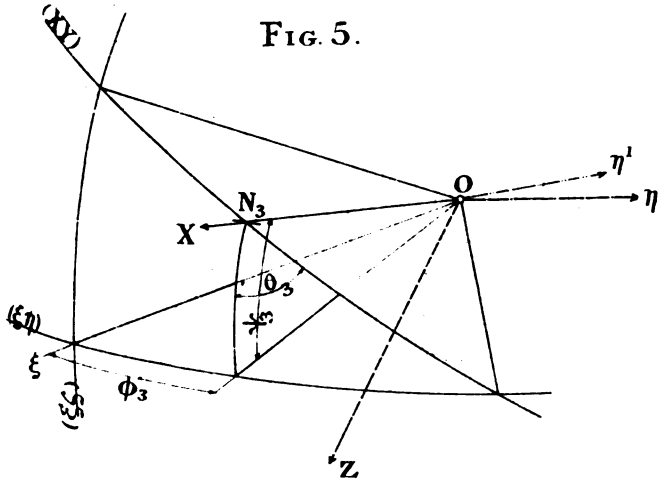

FIG. 5.

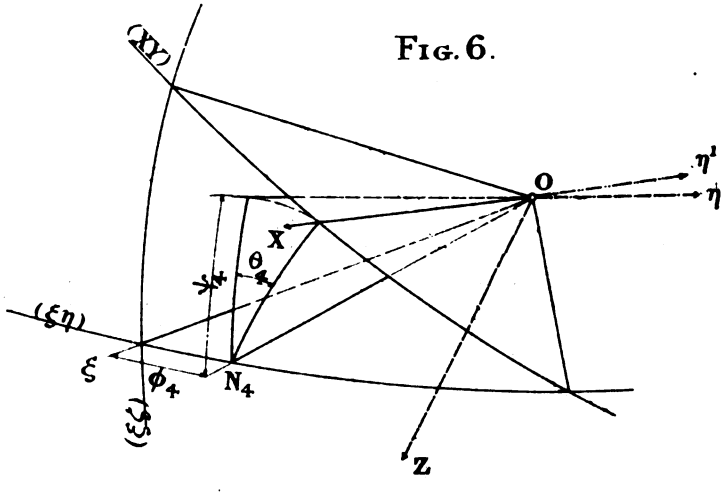

FIG. 6.

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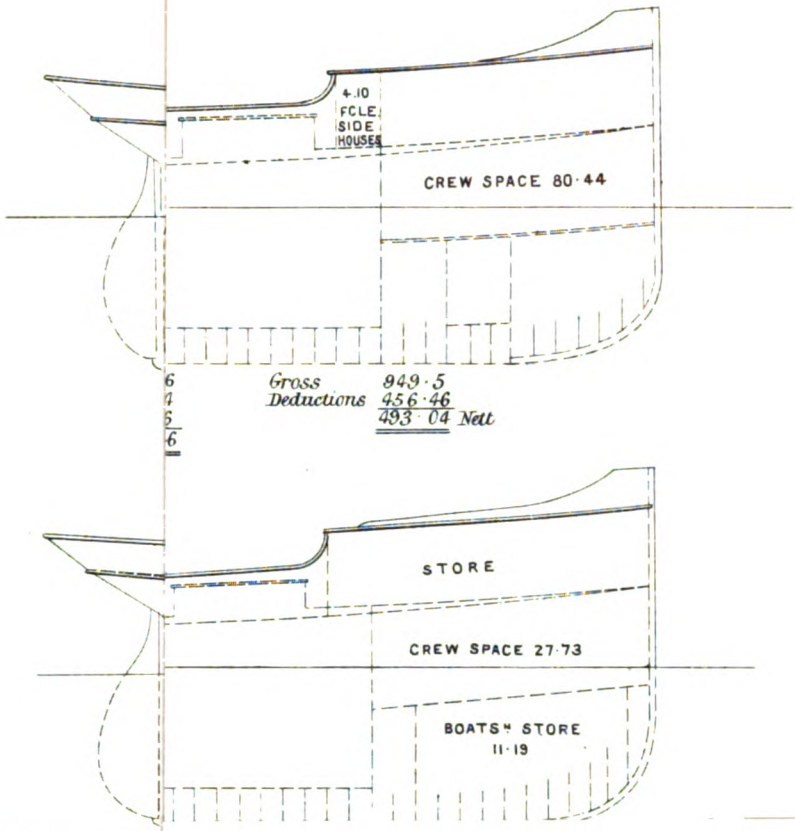
Plate XLIX.



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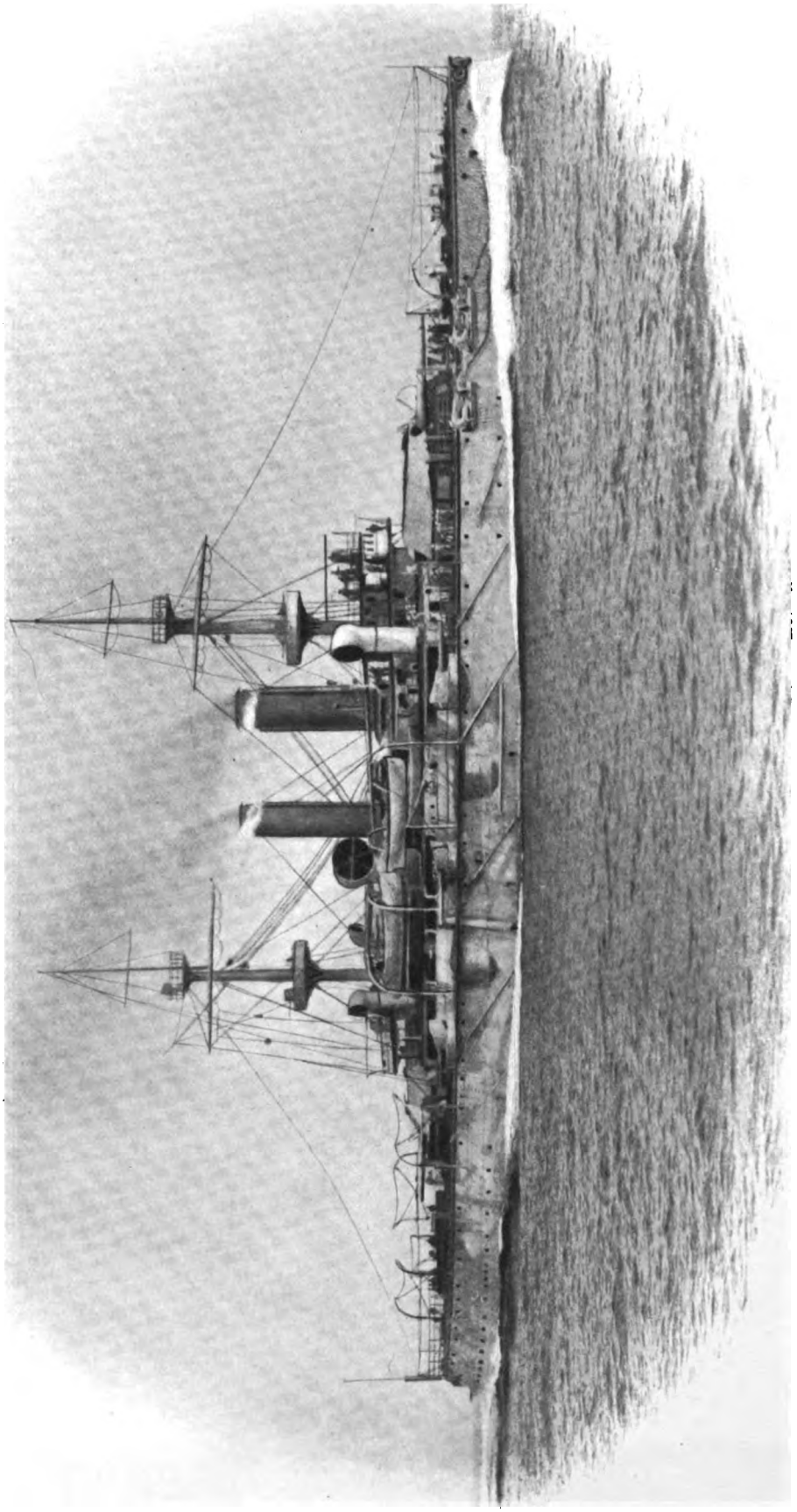
To illustrate Mr. Philip Watts' Paper: The Steering Qualities of the "Yashima."



H.I.J.M.S. *YASHIMA.*

Built by Sir W. G. Armstrong, Whitworth & Co., Newcastle-upon-Tyne, 1897.

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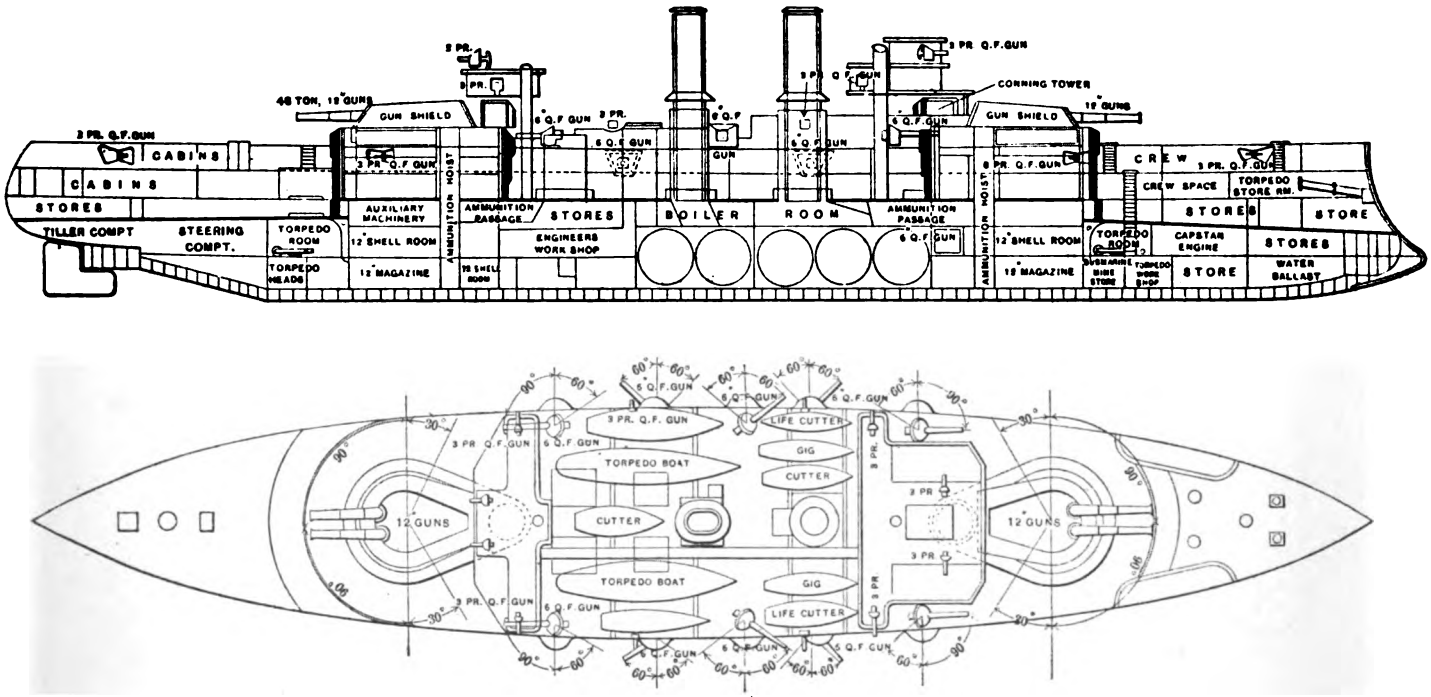
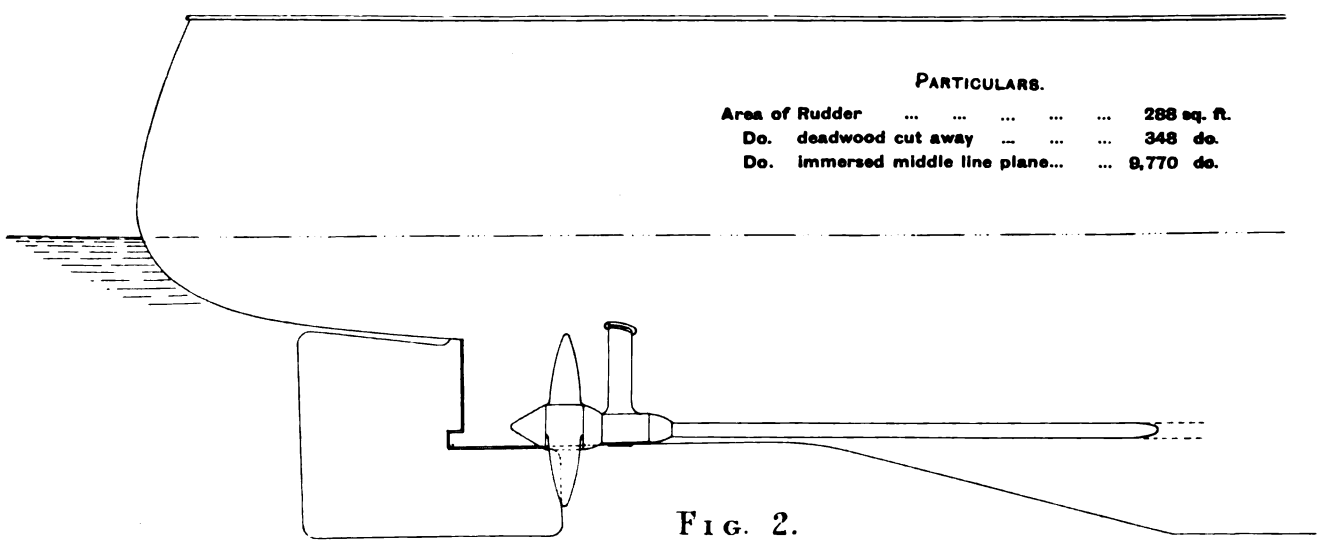
To Illustrate Mr. Philip Watts' Paper: The Steering Qualities of the "Yashima."



SECTIONAL ELEVATION AND DECK PLAN OF THE "YASHIMA."

FIG. 1.

"YASHIMA."—PROFILE OF AFTER PART, SHOWING SHAPE OF RUDDER AND DEADWOOD CUT AWAY.



PARTICULARS.

Area of Rudder	288	sq. ft.
Do. deadwood cut away	348	do.
Do. immersed middle line plane... ...	9,770	do.

FIG. 2.

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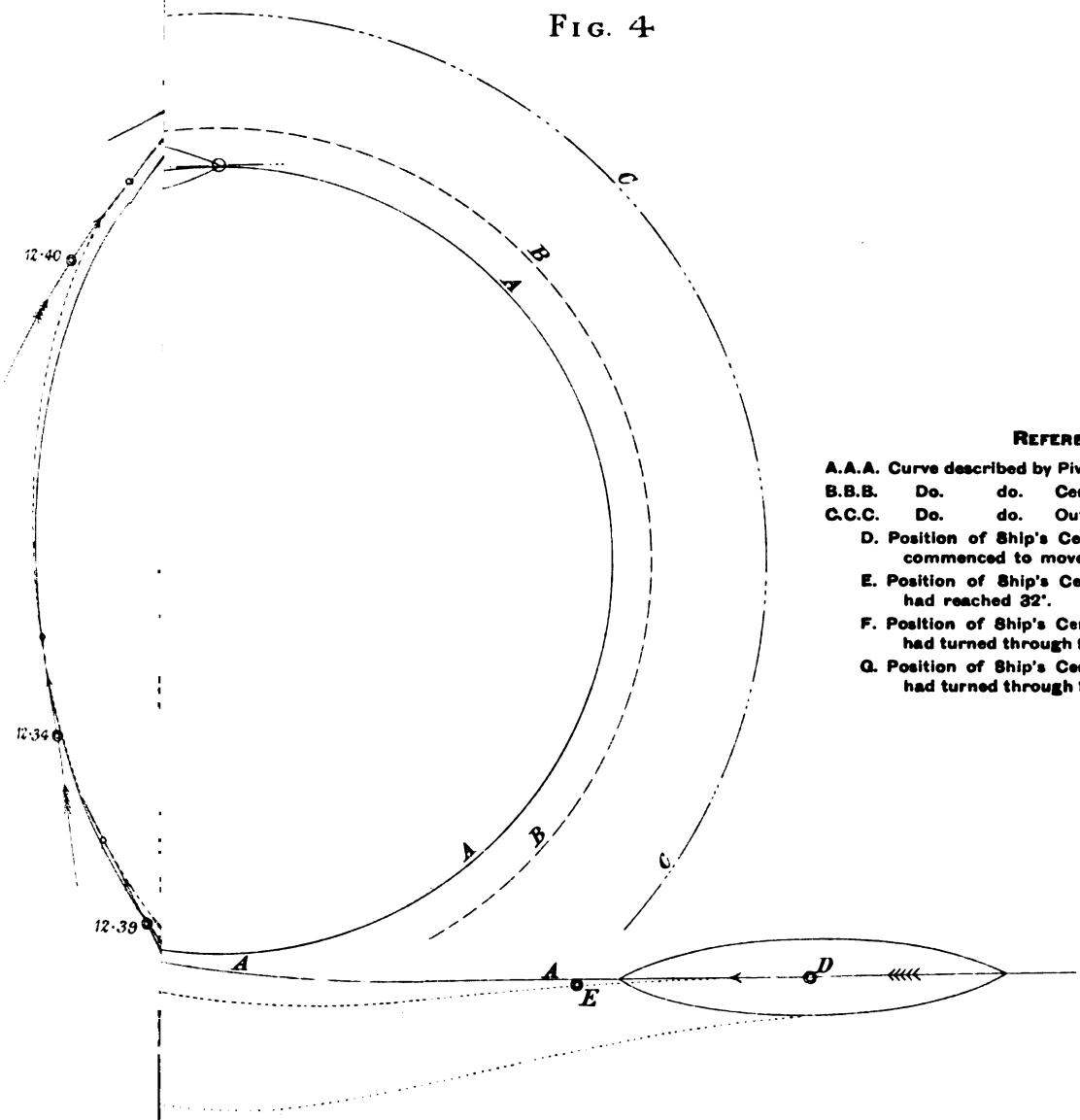
VERSED BY SHIP UNDER THE ACTION OF 32° OF HELM,
THE INITIAL SPEED OF 17·5 KNOTS.

FIG. 4



REFERENCES.

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E. Position of Ship's Centre of Gravity when helm had reached 32°.
F. Position of Ship's Centre of Gravity when vessel had turned through 90°. Time from D, 49½ s.
G. Position of Ship's Centre of Gravity when vessel had turned through 180°. Time from D, 1 m. 20 s

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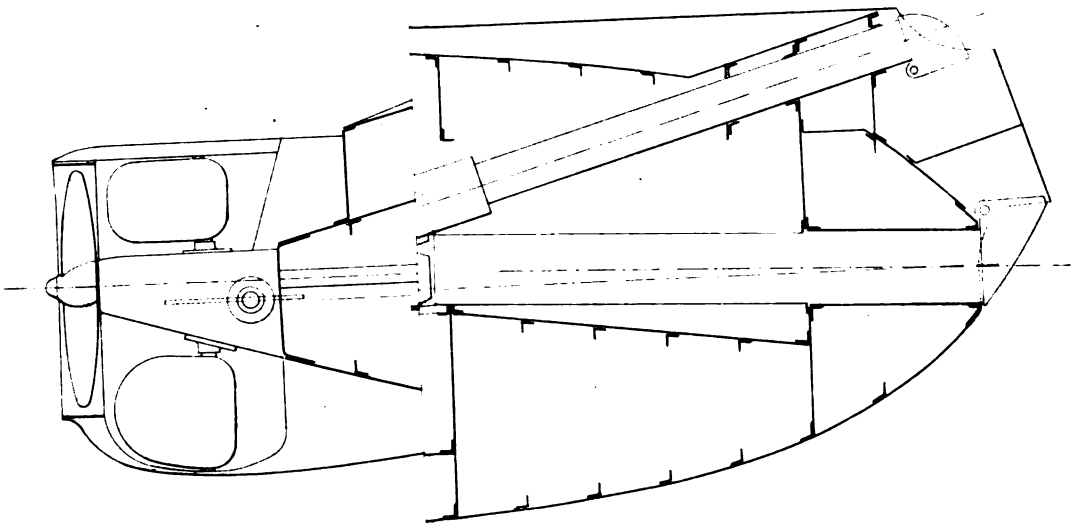

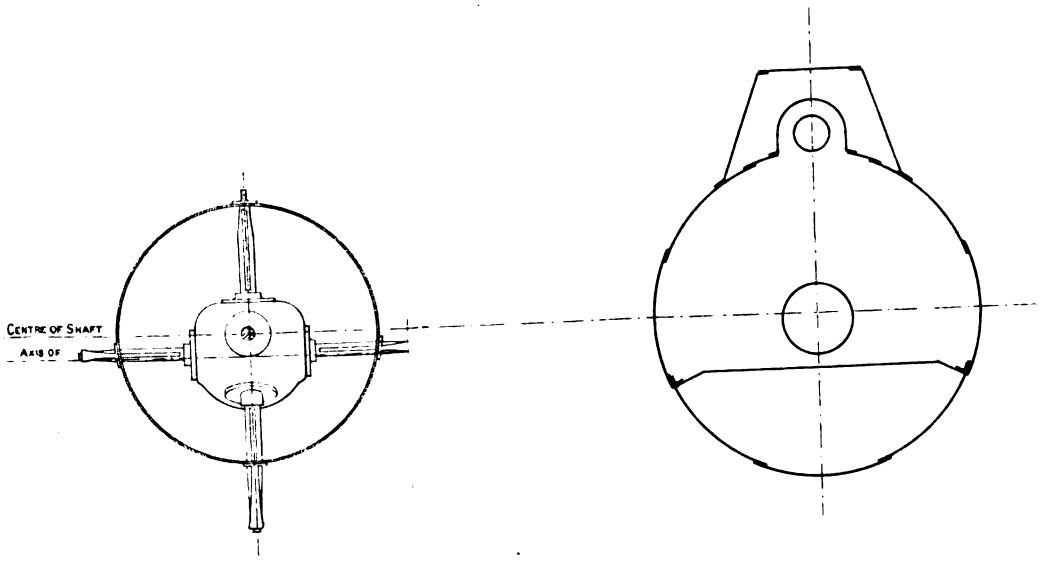

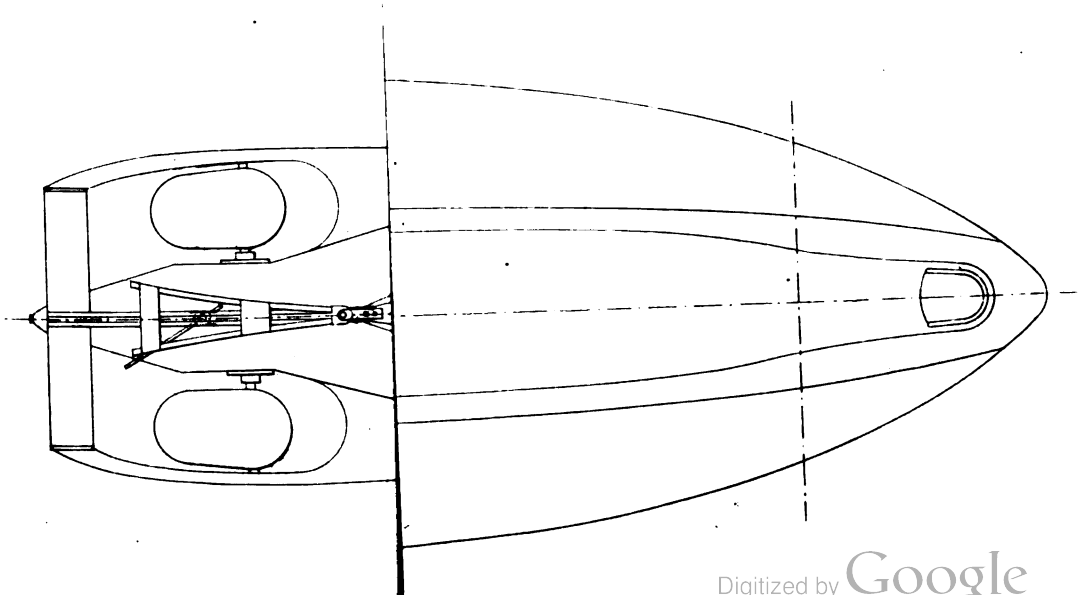

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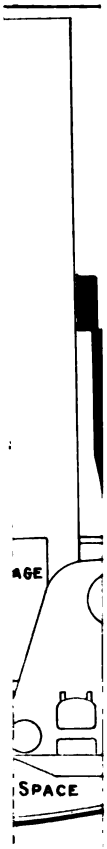

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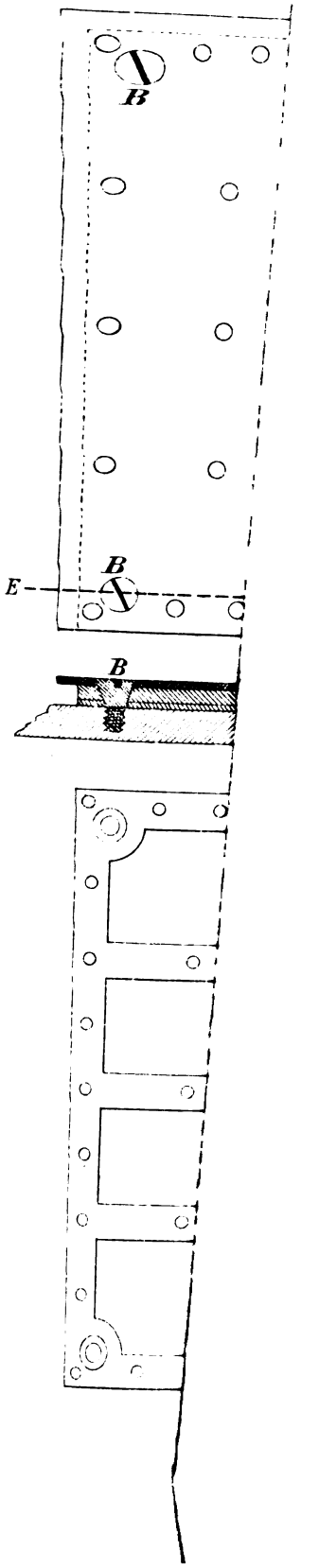

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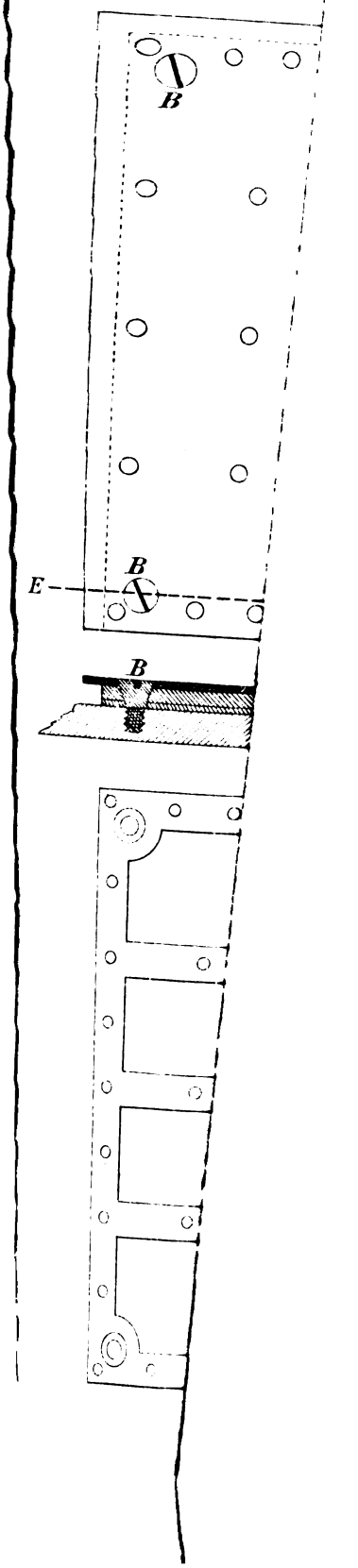

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